ENERGY MARKETS IN KENYA:

THE IMPACTS OF IMPERFECT MARKETS ON RURAL HOUSEHOLDS

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment of the Requirements for the Degree of

Masters of Science

by

Gregory Van Pelt Lane

August 2013

ABSTRACT

Energy is an essential component of nearly all economic activity and of modern society. However, throughout Sub-Saharan Africa limited access to modern fuels constrains consumers' ability to participate in economic activity, improve their livelihoods and enhance their quality of life. This thesis attempts to identify the inefficiencies in the energy distribution network that contribute to this problem.

To answer this question, this thesis attempts to provide a comprehensive picture of rural energy markets in East Africa, with a focus on Western Kenya. It begins by examining the macro-economic conditions that constrain fuel access in East Africa. This is followed by a quantitative investigation of the impacts of market imperfections on rural consumers by drawing on primary data collected from commercial centers in Western Kenya, the principal research area. Finally, it turns to study the energy consumption patterns of rural households.

Descriptive statistics and econometrics results indicate that poor transportation infrastructure and low access to the efficient distribution systems of oil marketing companies are significantly related to increasing the per unit price of fuel to rural consumers. Additionally, household fuel consumption behavior is largely found to follow the "energy-stack" hypothesis. These results underline the importance of increased investment in rural infrastructure and of increasing effective competition among oil marketing companies in order to more effectively provide modern fuels to rural consumers.

BIOGRAPHICAL SKETCH

Gregory Lane was born and raised in Philadelphia, Pennsylvania. He graduated from Tufts University in 2008. After graduation, he worked at Abt Associates in Washington D.C., where he managed USAID-funded projects in South Sudan, Ghana and Mozambique. After three years, he returned to school, attending the Dyson School of Applied Economics and Management at Cornell University. Gregory plans to pursue his Ph.D. starting September 2013.

ACKNOWLEDGEMENTS

This project has depended on the generous support of several individuals. I would first of all like to thank my two thesis advisors, for the guidance, feedback, and encouragement they have offered me throughout the writing of this thesis. In particular, I am grateful to David Lee for entrusting me with this project and for guiding me throughout the data collection and writing processes. His careful attention and assistance with the text and analysis are responsible for any polish exhibited by this thesis. Shanjun Li offered me crucial advice regarding the technical and econometric aspects of my work.

Frank Place was also instrumental in the development and planning of the research agenda. His long-term partnership with Cornell University has provided many opportunities for myself and others to conduct interesting research. The data collection process would not have been possible without the incredible work done by Stephanie Cadogan and Lilian O'Sullivan before my arrival in Kenya. I am very grateful the field team at the World Agroforestry Center (ICRAF), Kisumu for their kind assistance on the ground. Also many thanks to Yossie Hollander and the Fondation des Fondateurs for funding this research.

Thank you to my better half, Erin, who constantly helps me to further develop my ideas. To Julia Berazneva and David Guerra, for their sage advice, and for teaching me to take things in stride. To my parents, who have been a source of unfailing support.

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CHAPTER 1

INTRODUCTION

Energy is an essential component of nearly all economic activity and of modern society. However, billions of people lack access to cheap, reliable, and efficient sources of energy, which then limits their ability to participate in economic activity, improve their livelihoods and enhance their quality of life. This is especially true in Sub-Saharan Africa, where per capita energy consumption is the lowest in the world – 476 kilograms of oil equivalent (Karekezi, et al., 2004). The majority of Africa's poor continue to rely on traditional biomass fuels, such as firewood and crop residue, which are well known for their energy conversion inefficiencies. Poor households are often constrained to do so because the existing networks for more modern fuels such as petroleum products and electricity supplies are remarkably underdeveloped and inefficient. Ensuring that these households have better access to these fuels constitutes an important step towards increasing economic growth and overall welfare.

The purpose of this thesis is to identify the constraints in rural energy markets that prevent efficient energy access in Sub-Saharan Africa. We go on to investigate the impacts of market imperfections on rural consumers by drawing on data collected from commercial centers and households in Western Kenya, our principal research area. Finally, we suggest the areas that are in most need of investment to improve modern fuel consumption by poor rural households.

Governments and institutions alike can use this information to address inefficiencies and improve access.

1.1 Motivation

We focus our attention on East Africa specifically because the problems of energy access are particularly severe in this region. As of 2009, 81 percent of the East African population lived without access to modern energy[1] sources (Kirai and Hankins, 2009). The solutions to addressing this regional issue are exceptionally complex, and will become more difficult to solve as time goes on. Indeed, current trends in international markets, including higher prices and price volatility, are such that the access of the poor to modern energy sources may become steadily worse in the absence of effective interventions.

Globally, total energy consumption is increasing rapidly, which in turn is contributing to dramatic price increases. Fast-growing populations and economies in places such as China, India, and Brazil are driving this increased demand, and these trends look set to continue. Despite the economic slowdown since 2008, global energy consumption has continued to grow rapidly. Partly in response to this increased demand, the price of a crude barrel of oil has also increased steadily since it underwent a sharp drop in 2008. Over the past five years (2008 to 2013), the price of oil has risen 60 percent, and forecasters predict that high oil prices are here to stay (U.S. Energy Information Administration, 2011).

[1] Modern energy includes advanced fossil fuels such as petrol, diesel, and liquid petroleum gas (LPG) as well as electricity. For the purposes of this thesis, we will be mainly concerned about access to fossil fuels.

These price increases are strongly felt within East Africa for two reasons. First, as relatively small economies with low levels of oil consumption, these countries are unable to take advantage of economies of scale in fuel marketing and distribution. Taken together, the countries in this region constitute a very small percentage of global energy consumption. In 2008, for example, the entirety of Sub-Saharan Africa accounted for only 3.7 percent of total global oil demand. Second, barring the recent exception of South Sudan, the countries in the region are net importers of oil. As net importers, they face great difficulties in responding to oil price shocks. Governments are unable to capture any additional revenues from higher international oil prices through energy exports. Meanwhile, lacking sufficient domestic production to replace imports, they have little control over fuel supplies and prices (Rao and Lee, 2013). As a result, the majority of countries that are deemed most vulnerable to oil shocks are located in Sub-Saharan Africa (Bacon and Mattar, 2005).

In addition to these direct effects, fuel price increases also present significant *indirect* costs to consumers, and to poor households in particular. Fuels are an intermediate input in most consumer products purchased by households in the market. Indirect costs can be a particular problem for East Africa due to the poor state of infrastructure, as fuel price increases exacerbate existing inefficiencies. For example, these nations rely heavily on trucking to distribute consumer goods. Trucks rely on imported petroleum and diesel to operate, thus any increase in global fuel prices will augment delivery costs. These costs are then transmitted to end consumers of these products. Indirect costs from fuel prices are significant and can even exceed the direct impacts by a significant margin (International Monetary Fund, 2008).

In addition to achieving higher price levels, oil prices have also become more *volatile*. From 2005 to 2008, the price of oil increased by 146 percent, reaching a record high. In the aftermath of the financial crisis of 2008, the price of oil fell dramatically, only to rise quickly again as the world economy recovered. These fuel price shocks have had many negative consequences worldwide. High prices hurt consumers' purchasing power, caused fuel shortages, and even contributed to civil unrest. In many developing countries, price increases generated economic and political pressures for government response to lessen the impacts of high oil prices on their citizens (Bacon and Mattar, 2005).

On the whole, East Africa's poor are particularly vulnerable to the negative consequences of fuel price shocks and volatility. This is partly because poor households in East Africa spend a higher percentage of their income on fuel than anywhere else in the world, in some cases reaching 20 percent of total household spending (Howells, 2008). Furthermore, they typically lack the necessary savings to cope with even temporary price increases. In some cases price shocks even push current users of modern fuels to abandon them altogether (Maconachie, et al., 2009). Overall, increasingly high and volatile energy price levels deter households from adopting efficient energy, reducing economic opportunity and overall welfare for those affected.

Governments in East Africa, as well as international institutions, have sought to address the problem of increasing energy prices for various reasons.

Governments are generally concerned about the welfare of their poorer citizens and wish to provide them with better opportunities. Additionally, increased fuel access encourages overall economic growth, which is beneficial for the country as a whole. International institutions, such as the World Bank and bilateral donors, are also concerned with increasing efficient energy consumption as a path to poverty alleviation. Lastly, given that high levels of biomass use are associated with many environmental problems, such as increasing deforestation and carbon emissions, there have been increased international efforts to curb its use in developing countries.

Policymakers have used several approaches to increase sustainable energy access, to varying degrees of success. A primary approach is price assistance to the poor. This can take the form of subsidies or price caps on petroleum products, two common tools used by national governments to lower the price of modern fuels for consumers. However, fuel subsidies are not well adapted to help poor households and instead mainly benefit richer consumers who have already adopted modern fuels (Bacon, 2001). Additionally, price caps are often counterproductive in increasing access to fuel. Caps reduce the incentives for oil marketing companies (OMC) – private firms that are responsible for fuel delivery to consumers – to invest in distributing fuel to remote areas by limiting the levels of revenue can reap from these areas (Kojima, et. al., 2010).

Another common intervention supported by local African governments and international agencies has been expansion of the electrical grid. It is hoped that by extending the power grid, access to electricity will be extended to more households.

Unfortunately, despite these efforts, only about 10 percent of rural households have electricity connections (United Nations, 2005; Kaygusuz, 2011). High connection costs are the primary culprit that limits the ability of businesses and households to take advantage of increased physical proximity to electrical lines. In the absence of sufficient credit or payment schemes, most potential customers are unable or unwilling to pay the significant upfront cost of a new electricity connection (Schlag and Zuzarte, 2008).

Programs that promote renewable energy technologies such as solar and wind power are also common. These interventions seek to disseminate renewable power generators, such as solar panels, to rural areas. However, again, the high initial cost of investing in these technologies is often prohibitive for poor households. Additionally, the maintenance of relatively high-tech solar panels and wind turbines is also a problem in rural areas that lack the skilled engineers and parts to repair them (Deichmann, et al., 2011). Overall, while some of these programs have been moderately successful in promoting energy access, modern fuel consumption remains far below international standards.

1.2 Kenya: A Case Study of Energy Access

East African nations have pursued a wide range of policies, which have been met with varying degrees of success. These are well documented in the literature. Nevertheless, in order to gain a better understanding of market transactions within the distribution network, and successfully identify where failures lie, it is important to collect information at a more micro level. To this end, we decided to collect data on energy sales and uses from commercial centers and households from Kenya.

We focus on Kenya because it is typical of the region in many respects. Kenya has high levels of poverty, with 81 percent of its poor living in rural areas (International Fund for Agriculture Development, 2013). Also, like most countries in Africa, Kenya relies exclusively on imported crude or refined oil for domestic consumption. Energy consumption has increased in recent years, rising from 51 KBPD[2] in 2002 to 79.8 KBPD in 2010, thereby making Kenya one of the largest consumers of oil on the continent (U.S. Energy Information Administration, 2011).

Within Kenya, commercial centers serve an important function in ensuring that increasing fuel demands are met. Commercial centers are clusters of businesses in rural areas that are commonly found throughout East Africa. These centers function as markets and service providers for the local community, offering access to food, transportation, and other consumer goods. Some of the most important products they provide are modern fuels such as kerosene, diesel, petrol and liquid petroleum gas (LPG). Indeed, commercial centers typically serve as the only access point to the broader fuel distribution network for rural consumers. As a result, inefficiencies in these centers may have negative impacts on the price and access of fuels for the local community.

Kenya's poor, like those throughout East Africa, face many daily struggles. One of their most pressing concerns is a lack of access to modern fuels, a problem that is exacerbated by underdeveloped commercial centers. Indeed, modern fuels

[2] KBPD = thousands of barrels per day

are often sold at much higher prices in remote areas and are often not available at all in smaller villages (Chaurey, et al., 2004; Elias and Victor, 2005). Underinvestment in the infrastructure servicing these communities and the limited presence of oil marketing companies in rural areas are the chief causes of this problem. As a consequence of these constraints, rural households are often limited to using biomass as their sole energy source. Even high income households are forced to rely heavily on biomass, spending seven times as much on biomass energy as the top expenditure households in urban areas (World Energy Council and Food and Agriculture Organization, 1999; Pachuari, 2004).

While biomass fuels are more easily collected and cheaper than petroleum products or electrical power, they also present a number of drawbacks. First, the use of biomass has negative impacts on the environment. For example, the air pollution caused by burning biomass indoors is a serious health concern. As of 1999, 1.9 million deaths worldwide were blamed on rural indoor pollution every year while 450,000 deaths were attributed to urban indoor air pollution (Karekezi, et al., 2004). Second, biomass as a fuel is an inefficient source of energy. Kerosene delivers 3-5 times more energy per kilogram than firewood, while LPG is 5-10 times more efficient (Barnes and Floor, 1996). The inefficiency of biomass means households must collect large quantities of it to produce small amounts of energy.

Although biomass consumption has serious drawbacks, it is worth acknowledging that the consumption of modern fuels is also associated with significant negative externalities. The increased burning of petroleum-based products contributes mightily to the amount of greenhouse gases released into the atmosphere that are causing climate change. Additionally, the build-up of infrastructure necessary for delivery of modern fuels to consumers has negative spillovers such as increased road maintenance costs and local air pollution. However, despite these drawbacks, from an efficiency standpoint, fossil fuels emit lower amounts of harmful greenhouse gases per unit than biomass and so provide more energy for a given level of overall emissions (Schlag and Zuzarte, 2008). While the overall impact on the environment of increasing modern energy access and consumption in Sub-Saharan Africa can be debated, the primary focus of this thesis is to examine energy from an economic development point of view. Thus, I will leave issues related to the broader costs and externalities of increased fossil fuel consumption in East Africa to other researchers.

1.3 Research Objectives

For the reasons mentioned above, policymakers are looking to encourage the poor to move away from inefficient fuels such as firewood and charcoal, towards more efficient, healthier forms of energy. To accomplish this goal, two barriers must be overcome. First, modern energy must be made affordable for poorer consumers. Widespread fuel adoption will only occur when and if consumers can afford it. Second, access to modern energy needs to be increased in rural areas. Even if a household can afford commercial fuels, they will not be able to purchase them unless they are made available near where they live.

The main objective of this thesis is to identify and provide a quantitative understanding of the imperfections surrounding rural energy markets that make modern fuels unavailable to poor households. Using a unique data set from Western Kenya, we will isolate the specific attributes of the distribution network that impact both the price and access to fuel in rural communities. These can be categorized into two main groups. First are the policies and government institutions that influence the energy market. Second are the physical infrastructure and private firms that serve the poor. Furthermore, we look at how households currently make their fuel choice decisions. This allows us to better assess the impacts of fuel prices and access on households' behavior and welfare.

Through this process, we hope to fill a gap in the literature on energy markets in developing countries. The previous literature in this area has generally taken one of two approaches. The first approach has been to study energy markets from a broad, countrywide perspective. Oftentimes, studies examine the distribution system as a whole to identify bottlenecks and inefficiencies. However, the impact of these problems on consumers is often either assumed or ignored. The second approach focuses on the other end of the supply chain: households and energy users. Studies assuming this approach often analyze energy consumption and how households make choices between fuels. As a backdrop to this analysis, households are acknowledged to operate within the context of the broader energy distribution network, which limits their energy options. However, the impacts of these constraints on consumers are often not examined or quantified.

This thesis seeks to connect these two approaches to rural energy markets by examining the performance of local rural energy markets. Commercial centers, which are the focus in this research, link the broader distribution channels to households. By examining this link, we can better understand how well the energy supply chain serves these consumers. This, in turn, will inform policymakers about the best approaches and necessary investments needed to encourage the adopting of more efficient, healthier fuels among poor rural households.

1.4 Thesis Outline

The thesis starts with a broad overview of the main energy policies that influence East African nations' distribution networks of modern fuels. It then moves onto a discussion of Kenya as a representative case study for these nations. In doing so, we are able to draw on survey data that we collected from Kenya to identify the main barriers that prevent easy access to modern fuels. Next, we provide a detailed breakdown of the specific chapters that constitute the thesis.

Chapter 2 broadly describes government energy policies and the market environment in East Africa. These policies are important factors in determining the price of fuels and their availability in rural areas. In particular, we focus on Kenya and its three largest neighbors, Ethiopia, Uganda, and Tanzania. First we describe the laws and regulations that govern energy access throughout the region. Second, we detail the physical distribution systems for energy. Lastly, we cover the market structure of energy distributors. We conclude that there exist many problems that need to be addressed by the government and the oil marketing companies (OMC) before access can be dramatically improved.

The government and OMC's have a key role to play in terms of increasing energy access. Moreover, increased access in rural areas is also dependent on developing well functioning commercial centers. Chapters 3 and 4 offer a data-based analysis of these rural commercial centers in Western Kenya. Commercial centers are the connection between the distribution network and consumers, and can therefore have a large impact on the fuel prices paid by end users. The analysis starts in Chapter 3 by describing the types, quantity, and price of fuel being sold in the region. Additionally, we investigate where businesses purchased fuel, to whom they sold it, transportation costs, and any fuel shortages in the past year. To this end, we use data drawn from a survey conducted in the region surrounding Kisumu, Kenya during the summer of 2012. The survey includes information gathered from 1,438 businesses and 373 transporters on their energy transactions. The data set offers a novel cross-sectional snapshot of the energy markets in 56 commercial centers. We also take the opportunity to discuss energy demand from the different parties that either constitute or link commercial centers.

Chapter 4 provides a quantitative investigation of the factors that influence retail fuel prices in commercial centers. Analysis of the abovementioned data set also allows us to examine why poor consumers of fuels pay a higher per unit price than wealthier buyers. To investigate this further, we run regression analysis to quantify the factors that impact price formation. Specifically, we explore the effects of physical infrastructure, market competition, and access to OMCs.

Finally, Chapter 5 summarizes data on household consumption patterns and fuel choices. We begin by outlining the "energy stack" model of household fuel choice. In this model, as income rises households add more fuels to their "energy portfolio", but do not switch away from traditional biomass energy. We use this model to analyze household data from Western Kenya. The data was collected over a one year period (2011-2012) from 313 households located in the same research areas in Western Kenya as covered by the commercial center survey.[3] It is specifically used to examine the types and quantity of fuel consumed, household expenditure, and the percent of income that households spend on energy.

It is hoped that policymakers can use the analysis and results of this thesis to improve energy access for poor households. By identifying which market constraints have significant impacts on fuel prices, public resources can be better allocated to address the situation. Through needed investments in rural infrastructure and general policy changes, the overall efficiency of the fuel distribution system can improve. These efforts have the potential to significantly improve welfare for poor rural households and the economy as a whole.

[3] This data was gathered over a one-year period (2011-2012) by Julia Berazneva, PhD Candidate in Dyson School of Applied Economics and Management, Cornell University.

CHAPTER 2

EAST AFRICA ENERGY POLICY AND INFRASTRUCTURE

Access to efficient forms of energy is limited across Sub-Saharan Africa. This is especially true in rural areas. For example, less than ten percent of rural people have access to electricity in their households (United Nations, 2005; Kaygusuz, 2011). While access is greater in urban areas, intermittent supply and undersupply have hindered the development of large industries as firms face additional costs of investing in energy generation. In a 1999 study, for instance, Ugandan companies responded that inadequate energy access was the single most important factor limiting their growth (Collier, 1999).

The problem of energy access in Africa is largely due to a failure of infrastructure and institutions. The continent is home to large fossil fuel reserves from which are extracted large quantities of crude oil. However, these oil supplies are frequently exported for processing and then imported back into the region. Consequently, for every three barrels Africa produces, only one is consumed (U.S. Energy Information Administration, 2002).

This section reviews the current state of energy policy and environment in East Africa, in particular, Kenya. Additionally, the situations in Ethiopia, Uganda, and Tanzania will be described. These three nations are Kenya's largest neighbors in East Africa and can provide a broader context for how Kenya fits into the regional energy market. Together, these countries provide a useful comparison of available energy policy options and their consequences.

Our four focus countries in East Africa are almost entirely dependent on imports for their petroleum needs. As a result, they are particularly vulnerable to supply shocks stemming from events outside their control. While somewhat at the mercy of the international markets, there are several avenues through which countries can lower prices and increase access to energy. These fall broadly under two categories: domestic fuel policies and supply and distribution infrastructure. Domestic fuel policies primarily involve government regulation of imports, price controls and quality standards. Supply chain infrastructure takes into account the quality and efficiency of ports, pipelines, refining operations, roads, and market competition among oil marketing companies (OMC). Together these domestic factors have a large impact on the price and accessibility of fuels to poor consumers. Understanding the current state of domestic policy interventions and distribution infrastructure can help point to areas that may be unnecessarily increasing cost and decreasing access to fuels.

Table 2.1: Total Petroleum Consumption and Imports: East Africa, 2010[4]

	Total Consumption (2010) KBPD*	Level of Import (2010) KBPD*	Percent Consumption from Imports
Tanzania	30.7	30.7	100%
Kenya	79.8	52.2	65%
Uganda	23.0	23.0	100%
Ethiopia	43.3	42.5	98%

**Note: KBPD = Thousand barrels per day.*

To provide background to the proceeding discussion, it is important to first review the basic import and consumption figures for oil in each of our four countries

[4] Table 2.1 is adapted from Rao and Lee, 2013. Raw data come from the EIA database (www.eia.gov).

as presented in Table 2.1. Total refined oil imports into the region are small on a global scale, however, they are significant in the context of Africa. In all countries, except for Kenya, total imports are nearly equal to total consumption. Of the four countries, only Kenya has domestic refining capacity, which allows it to import crude oil in addition to refined petroleum products. As a result, locally produced products cover about 60 percent of Kenya's consumption. The largest importer of refined oil in the region is also Kenya, which imported 52.2 KBPD (thousands of barrels per day) in 2010. Kenya was followed by Ethiopia, which imported 42.5 KBPD, then Tanzania, which imported 30.7 KBPD, and finally Uganda, which imported 23.0 KBPD.

The following section will examine recent developments in energy policy and infrastructure in Kenya and the surrounding countries. The section will be divided into two parts. The first part will provide a detailed overview of the various different policies that have been used to ensure safe and efficient fuel access in the region. These policies cover a wide range of topics, which include strategies for importation and procurement, price schemes, and safety and quality regulations. The second half of the section will summarize the physical distribution systems in these nations. More specifically we review the physical infrastructure currently in place, and the competitiveness of the distribution companies that are responsible for managing the supply chain. The various topics covered in each of the two parts will be presented in the same way. We will first summarize the current state of affairs in the surrounding countries. This provides additional context for understanding how Kenya's policies and infrastructure have evolved. Then we will go into more depth about the situation in Kenya and how it came to be.

2.1 Fuel Policy

2.1.1 Imports and Procurement

Ethiopia, Uganda, Tanzania and Kenya represent important and sizeable economies in the African context. However, they are only small players on the international scene. This distinction applies to most commodities, including the market for oil. While these countries import large quantities of oil relative to other African nations, their total consumption represents a very minor share of global demand. As a result, these four countries have struggled to achieve economies of scale in importing and distribution, which would allow them to improve the efficiency of the importation process to international standards. Indeed, if they could put through larger orders they could reduce transaction costs, and afford to upgrade port infrastructure. Different countries have pursued different strategies to enhance scale economies. Three of our focus countries, Ethiopia, Tanzania and Kenya, have chosen to assign a single buyer for petroleum. In theory, by allowing a single buyer to purchase petroleum for the entire economy, a better overall import price can be obtained. This results in cost savings for the industry as a whole, as well as ensuring easier collection of import duties. Uganda, on the other hand, has pursued a fairly liberal strategy of leaving the importation of petroleum up to the market.

Ethiopia and Tanzania have taken two different approaches to establishing a single buyer. Ethiopia uses a parastatal oil company, Ethiopian Petroleum Enterprises (EPE), as the only legal importer of oil products. EPE is then responsible for supplying other oil marketing companies within Ethiopia. Tanzania, on the other hand, recently installed the more market-oriented Bulk Procurement System in 2011. Under this system, the government issues a bi-monthly contract allowing one company to be the sole importer of oil for those two months. Private companies are invited to bid on the contract and the lowest bid wins. This single company is then responsible for distribution to the other OMCs.

In contrast, Uganda has liberalized their procurement policy, which allows individual companies to purchase their supply directly from the international market. This free market approach is a result of Uganda's general *laisse faire* attitude towards energy markets. As a landlocked country, Uganda relies entirely on Kenya for access to imported oil. This makes it extremely difficult to transport the oil they purchase from Kenyan ports back across their borders. Moreover, each individual company must make small orders and transport these smaller amounts independently. As a result, there are very few prospects for Uganda to take advantage of economies of scale (Kojima, et al., 2010).

Kenya uses a system very similar to Tanzania's. The Kenyan government presides over two "Open Tender Systems", which are both open to private OMCs. The first Open Tender System is for crude oil and the second is for refined oil. This system is unique in the region and is the result of Kenya's access to their own refinery that processes crude oil. The government also requires that 50 percent of countrywide demand for refined products be met by the domestic refinery.[5] The remaining demand is met through direct imports of refined products, also through the Open Tender System. In each tender system, private companies bid every month to become the sole importer for the entire market. Once the winning firm imports the petroleum, it is then split among all OMCs proportionally based on their market share.

The Open Tender System in Kenya has partially allowed the country to take advantage of economies of scale, decreasing the disadvantage presented by their small market size. Furthermore, the Open Tender System has made some progress in reducing tax evasion and decreasing the import fragmentation that increases costs. Nevertheless, concerns remain over numerous inefficiencies that have yet to be resolved. This is especially true in Mombasa, Kenya's main port, where delays in assigning contracts, insufficient capacity to offload fuel, and delays in government inspections of offloaded fuel all increase costs. These problems have even led to fuel shortages in Uganda, which relies on Kenya to transport the majority of its imports (*The Citizen*, 2010).

2.1.2 Price Policy[6]

Pricing strategies for fuels have traditionally been one of the most widely used public policy tools to encourage fuel access. These polices can be effective poverty alleviation tools if they are targeted at poor households, for example, by

[5] This law was recently changed in July 2012. The refinery is now able to purchase crude oil directly from the private market rather than only sourcing from local OMCs. It is hoped that this will allow the refinery to source cheaper crude oil.

[6] The material presented in this section draws extensively from Kojima, et al., 2010 and Bacon, 2001.

subsidizing fuels such as kerosene. However, they may be regressive if they target fuels used by wealthier households such as petrol. Additionally, these subsidies can also be extremely expensive and difficult to maintain on a fiscal basis. Direct subsidies become particularly problematic when price shocks occur and the cost of maintaining the subsidies soars (Coady, 2006).

An alternative policy to using direct subsidies is price controls. These polices are widely used across Sub-Saharan Africa and are comprised of two basic features. The first is a price structure that uses import parity as its baseline. Import parity requires setting the price of fuel equal to its cost at the point of import, which includes international transport costs and tariffs. Countries then vary by how many additional costs they include in the fixed price (such as transport, storage, and margin costs). The second component is the adjustment mechanism, which periodically moves the fixed price based on market parameters such as exchange rates, international prices, and interest rates. Generally, governments adjust the price automatically on a monthly basis (Rao and Lee, 2013).

Price controls can either be set regionally or as "pan-territorial" prices, meaning that the price is set uniformly throughout the country. While pan-territorial pricing is easier to enforce, it also creates strong disincentives to expand markets into remote areas, as firms will be unable to capture the transportation costs of delivering fuel. While more flexible, regional pricing also has the effect of reducing investment in rural areas. Due to fixed profit margins, companies are typically unwilling to invest in less populated areas as they may be unable to recoup a positive return on investment. Instead, companies will often focus on densely populated areas where they can experience a higher volume of trade. Usually, OMCs are allowed to sell fuel at a locally competitive price as long as it does not exceed the price cap.

East African stands out on the continent as having relatively liberalized pricing policies, although pricing regimes have undergone many recent changes. Tanzania has vacillated between controlled and liberalized price regimes. In 2000, the government removed price controls on petroleum products and moved to a liberalized regime. However, the severe commodity price rises experienced in the following decade prompted a return to price controls in 2009. Tanzania is exceptional in that the regulatory agency (The Energy and Water Utilities Regulatory Authority of Tanzania) regularly publishes regional price caps and their method of price calculation on its website. This level of transparency is uncommon both within the region and elsewhere in Africa.

Ethiopia also follows a regime of price controls. Under the auspices of the Ministry of Trade and Industry, retail and transportation price levels for fuel are set based on appeals from the state and private OMCs. Adjustable variables such as taxes, levies, and transport margins are also used to influence retail prices. Until 2008, Ethiopia heavily subsidized fuels, especially diesel and kerosene. However, the massive fuel price rise of the mid-2000s proved too expensive for the government to continue. In October of 2008, the government changed prices to be higher than the import cost to allow the Oil Stabilization Fund to pay down its debt (GTZ, 2002). Since then, the government has attempted to balance price stability and efficiency through frequent price adjustments.

Similar to its approach to fuel imports, Uganda does not impose price restrictions on fuel. Market prices reflect the import costs of petroleum, transport costs, profit margins of OMCs, and government taxes.

Turning to Kenya, from 1994 – 2010, the country had liberalized fuel pricing. However, like Ethiopia and Tanzania, the commodity price crisis of the late 2000s spurred Kenya's government to introduce price controls. Their recent approach to fuel prices most closely resembles that of Tanzania. In 2010 the Energy Regulatory Commission was given the power to regulate retail prices of petroleum products sold from the pump.[7] Retail price caps are calculated on a "cost-plus" basis. Starting at the price quoted by the importing OMC, costs are added for importing expenses (wharfage, customs fees, etc.), taxes, transportation costs, and allowable industry margins to arrive at the final retail price at the pump. It is important to note for the subsequent analysis that price regulations are only enforced at gas stations and any downstream fuel sales are not price-controlled (GTZ, 2009).

The newly implemented price controls in Kenya have not been without controversy. Small retailers, who are excluded from the Open Tender System, have accused larger OMCs of excluding them from the market. Importers are allowed to fix their wholesale prices above the recommended retail price, as the law does not control wholesale prices. In effect, this excludes smaller OMCs from the market (*The Star*, 2012).

Governments have a delicate balance to achieve with their pricing policies as they seek to accomplish two competing goals. The first goal is to ensure access to

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[7] The law was passed in 2006, but did not take effect until 2010.

fuels for the population while the second is to generate government revenues through taxes. Fuel taxes have traditionally been a very important part of developing countries' revenues because they are relatively easy to collect. Often the taxes gained from petroleum products are critical sources of revenue for underfunded governments. However, taxes on fuel are often a significant part of total retail costs. Clearly then, there is tension between the goal of supporting households through the application of price controls and that of increasing government revenues through increases in fuel taxes. In order to address this conflict, fuel taxes are generally tiered, with the highest taxes being applied to gasoline (a fuel used by wealthy households) and the lowest taxes being applied to kerosene (a fuel used by poorer households).

Petroleum taxes in the region are generally high based on global standards. In Tanzania, government taxes make up about 25 percent of the calculated price cap. Uganda has the highest taxes in the region; they implement an excise duty of 850 UGX[8] per liter of petrol. The taxes are targeted, so that gasoline is taxed at a twice the rate of kerosene. In contrast, Ethiopia imposes very low taxes on fuel, likely due to its legacy of subsidization.

Kenya has overall high levels of petroleum taxation. The government breaks down the taxes on petroleum into three categories. The largest, accounting for 19.8 percent of the total mark-up on imported petroleum, is a general excise levy. This is followed by the "Road Maintenance" levy (9.1 percent) and the "Petroleum

[8] 850 UGX is equivalent to $0.33 (US) using exchange rate as of May 1, 2013.

Development" levy (0.4 percent). In total, taxes make up approximately 30 percent of mark-up on the imported price of oil (GTZ, 2009).

2.1.3 Regulations And Enforcement

General Laws and Regulations. Petroleum markets are heavily regulated in the four East African nations of interest here. A strong and effective set of laws is a necessary condition for an effective market as they provide the framework under which firms compete. These laws regulate fuel labeling, quality and safety, as well as transport systems and distribution installations. As a result, the legal framework has widespread impacts on how easily petrol can be accessed and the prices that are charged for different fuels. The degree and quality of these regulations varies widely across Sub-Saharan Africa. Even in countries that have updated their regulations, effective enforcement remains a problem due to funding and technical constraints (Kojima, et al., 2010).

The majority of countries in the East Africa have created specific government agencies that are in charge of implementing the regulations that are passed. As a result, the institutional frameworks within the countries of interest are generally considered to be strong. The laws themselves are also well-designed and successfully target fuel safety and quality. The primary problem lies in the disconnect between the laws and institutions that are in place, and their enforcement on the ground. While most regulatory institutions have the appropriate mandates, they lack the necessary funds and ability to enforce existing laws. Of the four focus countries, only Tanzania is reported to have strong enforcement and oversight (Kojima, et al., 2010). For example, in its annual report, Tanzania's regulatory agency provides the results for product quality tests, the number of operators and installations, and the capacity and condition of each installation (Briceño-Garmendia, 201). There is very little information about Uganda and Ethiopia's enforcement strategies. Anecdotal evidence would suggest that they are lacking. Indeed, there exist a few reports that point to instances of unsafe gasoline stations and overly diluted fuel that has damaged engines (Foster, 2010; *Saturday Monitor*, 2013). Furthermore, some articles have reported incidents of fuel smuggling whereby businessmen import illegal amounts of petroleum and bypass taxes and quality checks (Kojima, et al., 2010).

In Kenya, the Energy Regulatory Commission (ERC) is specifically mandated to enforce fuel laws. This institution has now been in place for several years since its establishment in 2006. Furthermore, the set of laws that are currently in place recently underwent a drastic overhaul. Prior to 2010 the laws in Kenya were largely holdovers from British colonial rule, which were outdated and insufficient for a modern energy market. In 2010, Kenya began to roll out new quality and safety regulations to be enforced by the ERC. These new standards include improved environmental, health and safety standards, with one of the most important regulations dictating the amount of ethanol blended with each gallon of petroleum. In addition, a recent 2011 regulation requires that gas stations have more reliable safety mechanisms and operations. On the surface, the system seems to be functioning well thus far. Nevertheless, many of the new regulations are still being drafted, and it is too early to judge whether or not they are being adequately enforced. In general, there is a lack of literature on Kenya's enforcement mechanisms on the ground. In the next few years, once all the laws are adequately stipulated, one would expect more information to surface regarding the government's successes and or failures in implement them.

Transportation Laws and Regulations. Some of the most important regulatory polices within each of these countries concerns fuel transportation. We present this case separately because of how crucial transportation is in determining fuel prices. Trucking is by far the most prevalent method of petroleum distribution in East Africa. However, the industry faces many problems, including overburdened trucks, poor road infrastructure, and excessive roadblocks (Foster, 2010). This is consistent throughout the region and, as a result, these countries have developed a detailed set of laws that regulate the maximum weight that trucks may carry. These laws are designed to limit the number of trucks that break down and to reduce road degradation. However, as we have seen previously with regulations and laws in general, enforcement remains the main concern. Indeed, regulations are rarely enforced and when they are, it is often in an attempt to exhort bribes from truck drivers. Failure to enforce transportation-related laws is particularly problematic as it leads to a vicious cycle where the deterioration of road infrastructure decreases the incentive even further for trucking companies to invest in their fleet, and further encourages overloading as the cost of a single trip increases. The poor fleet quality then causes more road destruction (Kojima, et al., 2010).

There have been some instances, particularly in Kenya, where axle load limits[9] have been more strictly enforced. Nevertheless, this effort has also been problematic and produced its own set of consequences. For example, Kenya ran into sizeable problems when it attempted to strictly enforce its axle load limits in 2008. By reducing the amount of weight trucks could carry, many fleets were no longer able to transport the same quantities they had in the past. As a result, Kenyan trucking companies could no longer deliver adequate fuel supplies to their land-locked neighbors and Uganda subsequently experienced a fuel shortage (Dow Jones Commodities Service, 2008).

A strict enforcement of axle load limits can impose significant short-term costs. Nevertheless, on balance, the long-term gains from enforcing truck weight laws will dramatically outweigh these short-term costs. They will lower infrastructure repair costs, reduce accidents, and can eventually lead to the adoption of a better-maintained and more efficient trucking fleet.

2.2 Fuel Distribution

2.2.1 Infrastructure

It is vitally important that nations work towards improving the distribution infrastructure for petroleum in order to ensure that supplies are reliably and affordably supplied to consumers. This is especially true in East Africa where countries rely almost exclusively on imported oil (Kojima, et al., 2010). Imported oil enters the region via the main ports in Kenya and Tanzania and is distributed

[9] Axle load limits restrict the amount of weight a truck may carry based on the number of axles on the vehicle.

throughout these countries and neighboring Ethiopia and Uganda. As it stands, the channels through which these resources must travel are complex yet under-developed. The existing inefficiencies throughout the supply chain often result in higher prices for fuel by the time it reaches the consumer. These East African nations need to improve the infrastructure they use for the distribution of petroleum in order to mitigate these price hikes.

The only alternative to improving the existing supply chain is to develop domestic production, which would replace imports. Domestic production would make it easier to supply oil by shortening the distance the commodity needs to travel, thus, presumably, lowering the price. This would make these countries less vulnerable to the pitfalls of a complex cross-country distribution infrastructure. It is worth mentioning that there have been some recent discoveries of oil in Uganda and Kenya. However, the amounts that can potentially be extracted will not meet region-wide demand in the foreseeable future. Moreover, there is only one refinery in the region and there are no long term plans to build more. As it stands, this refinery would be unable to process even the limited amounts of crude oil these countries currently produce. Overall, the prospect for reducing dependence on imported oil is limited in the near future as expanding production and processing capacity is difficult to achieve and is highly capital intensive (Bacon, 2005).

In the short to medium term, Tanzania, Uganda, Kenya and Ethiopia will thus have to continue to rely on imported oil. It is therefore vital that they make the existing the supply chain more efficient, and specifically target their resources towards improving the distribution infrastructure, which is currently plagued by many different problems. The petroleum supply chain in East Africa can roughly be divided into three separate sections: refining, wholesale, and retail. The capability of these three sectors, and the transportation infrastructure linking them together, is critical for increasing supply chain efficiency. The transportation infrastructure includes pipelines, rails and trucking networks that link each stage together.

Of the four East African countries of interest, only Kenya's supply chain begins both at the refinery and in the ports. Tanzania is able to import directly from international markets while Ethiopia and Uganda must rely on shipments from their neighbors. We will begin by discussing Kenya's unique refinery access and the prevalence of problems that plague it. We will then move on to discussing the infrastructure that defines the next stage of the supply chain and which is common to all four nations, namely pipelines, rail and roads.

Refineries and Ports. The Kenya Petroleum Refineries Ltd. (KPRL) operates Kenya's only refinery, located in Mombasa. KPRL is widely considered to be inefficient and is unable to compete at an international market level (Kojima, et al., 2010). Generally, a refinery needs to reach a capacity of 100,000 barrels a day in order remain competitive and KPRL is unable to attain this benchmark (*Oil and Gas Journal*, 2009). Additionally, the refinery has no cracking capacity (cracking is a process which uses catalysts to produce higher quality "light" products such as gasoline). This then limits its ability to match market demands for more highly processed fuels. Finally, water and electricity shortages often disrupt the refinery's operations. This has created petroleum shortages in the region. In 2009, for example, electricity shortages were so severe that the Kenyan government ordered the refinery to produce its own electricity because the state electrical company was unable to provide sufficient levels to the site (*Daily Nation*, 2009). This requirement had very negative consequences for the refinery's own operations. The Kenyan government has tried to protect this refinery despite the many problems that plague it and that limit its inability to compete internationally. For example, in the 1990's Kenya originally called for 70 percent of domestic consumption to be processed through KPRL. This plan proved unsustainable and subsequently failed, with the result that the requirement was lowered to 50 percent.

Tanzania, Uganda and Ethiopia do not operate a refinery and their distribution networks begin solely at the ports. Kenya also relies on its ports for any fuel that is refined abroad. In Tanzania and Kenya's case, importing refined petroleum is fairly straightforward: imported petroleum arrives by sea and is then transported throughout the country via pipelines, rails and road. Currently, the two main ports for each country are located in Mombasa, Kenya and Dar es Salaam, Tanzania. These ports have enough receiving capacity to successfully serve regional markets. Uganda and Ethiopia face an additional challenge. Once the cargo vessels are docked at the ports, importers must rely on exclusively rails and road to transport their commodities all the way across neighboring nations before they can gain access to them. Not only are roads and rail less efficient than pipelines, but the long distances add extra costs and additional uncertainty in the supply of fuel to Uganda and Ethiopia. Many instances have been reported of bottlenecks and rent-seeking activities along the supply chain, sometimes resulting in fuel shortages (Briceño-Garmendia, 2011).

Pipelines. Pipelines tend to be the most cost effective way to transport fuel overland. Within our four focus countries, they are only used by Kenya and Tanzania, as they are the only two countries that have pipelines built in East Africa. Kenya has a 30-year-old pipeline running from Mombasa to Nairobi while Tanzania runs a pipeline running from Dar es Salaam into Zambia. While pipelines are generally most efficient form of transporting petroleum, both East African pipelines are poorly maintained and often operate well below capacity. In particular, the Nairobi-Mombasa pipeline has often operated at only 50 percent capacity due to an erratic power supply and a backlog of maintenance (Foster, 2010).

Rail and Road. Less efficient alternatives to pipelines include rail transport and trucking. The availability of rail transport is limited in the region and where it exists, it is underutilized. Tanzania, Ethiopia, and Uganda all have rail transport but each country fails to make adequate use of this system. Railroads in these countries have been left to fall into disrepair because of poor management and insufficient resources.

Kenya is typical of the region in this respect. Kenya's major rail corridor links Mombasa, Nairobi, Kisumu, and extends to Uganda. While this is a vital trade corridor, the rail line is in shambles and only carries one million tons a year. Among the major challenges are inadequate rail-port infrastructure, general track deterioration, and a lack of an experienced rail company to handle operations (Briceño-Garmendia, 2011).

By far the most common means of distributing petroleum in these four East African countries is by truck. While ubiquitous, trucking faces several constraints that increase transportation costs and reduce reliability in all four nations. First is the problem of overloading by trucking companies. Trucking fleets are typically old and poorly maintained, and it is common for trucks to carry loads well over their designed capacity. Companies are motivated to pursue this policy to increase total fuel delivery per trip and also to avoid official and informal road tolls. While this practice has the benefit of short-run cost savings, it increases long-run costs by causing more accidents and breakdowns. Second is the problem of poor road infrastructure. Very little money has been poured into improving the physical conditions of the roads across the region, as well as their overall safety. Conditions on the roads are steadily getting worse, with one of the primary culprits being the overburdened trucks, which cause great damage on both, paved and unpaved roads. In the long run, greater road deterioration increases the transport time of fuel and inhibits the use of more efficient higher weight trucks (Kojima, et al., 2010; Foster, 2010).

Kenya's major road network suffers similar problems despite being well-established and providing basic regional and international connectivity. The road system also benefits from periodic maintenance efforts, which are supported by a dedicated funding source drawn from petroleum taxes. Nevertheless, the overall quality of roads remains quite poor and there is a large backlog of roads in need of rehabilitation. Exacerbating this problem is poor oversight of road construction contracts, which has led to poor and short-lived road improvement projects. Additionally, beyond the trucking network linking major cities, road accessibility is poor. As a consequence, only 30 percent of Kenyans live within two kilometers of a paved road (Briceño-Garmendia, 2011).

As mentioned earlier, Kenya has periodically tried to address some of these problems. The most emphasis has been placed on attempting to enforce their axle load law in order to reduce road deterioration. Unfortunately, this has done little to solve the problem and has created other difficulties. In 2008, this increased enforcement actually resulted in fuel regional shortages. More recently, it sparked a protest by truckers outside Mombasa in December 2012 (*The Star*, 2012).

2.2.2 Market Competitiveness[10]

Once petroleum arrives in the ports, or in Kenya's case leaves the refinery, private firms take responsibility for its transport and distribution. The number of firms that participate in the oil supply chain varies across countries and the concentration of firms in any given market can have a significant impact on price. Indeed, as the number of firms increases, there will be more competition in the market, which in turn, will force companies to become more efficient. In general, East Africa has relatively concentrated distribution markets with a few firms controlling most of the supply. There is a strong disincentive for new companies to try to break into these markets because local demand is insufficient to offer a worthwhile return on investment. As a result, these East African nations are left with a small number of large companies that run the entire supply chain. They have little incentive to improve their efficiency, and this leads to an increase in fuel

[10] This section draws extensively from Kojima, et al., 2010.

prices. In addition, this causes chronic underinvestment in rural areas as firms fail to improve their distribution networks in remote areas.

The market has suffered from this lack of competition for decades. This is most explicitly quantified by the Herfindahl-Hirschman index (HHI). The HHI is a statistical measure of market concentration and is commonly used by the U.S. Department of Justice in the analysis of the competitive effects of mergers (Rhoades, 1993). The HHI is calculated by squaring the market shares of each company and summing them together, as follows:

$$HHI = \sum_{i=1}^{N}(MS_i)^2$$

In the above equation *"MS"* is the market share of each firm. For example, if four firms controlled equal 25 percent shares of the market the HHI would be calculated to be 2,500 while a monopoly would present a maximum value of 10,000. A market with an HHI above 1,800 is generally considered to be concentrated, while a score of 1,000 or below is unconcentrated. Calculating the HHI index for our study area shows that three of the four East African countries exceed the concentration benchmark of 1800. Uganda has an HHI of 1,831 while Kenya is slightly worse with an HHI of 1,937. In both of these countries a small number of private firms dominate the market, consigning smaller firms to the periphery. Ethiopia also has a highly concentrated market, although the exact HHI score is unknown. This is due to the monopoly that the parastatal Ethiopian Petroleum Enterprises has on imports, which deters many firms from entering the market. As a result, four large transnational firms control most fuel distribution. Finally, Tanzania is the only country in our study group to be considered unconcentrated with a HHI score of 1,107. Tanzania has 25 firms that operate in the market, with the largest firm controlling only 16 percent of the market (Tordo, 2011).

Each country has had slightly different attitudes towards market competitiveness. Ethiopia, for example, has little incentive to encourage private competition due to the presence of its state supported oil company. The government is currently able to capture the large revenue stream from the distribution and sale of the imported fuel. Any private competition would result in a reduction of this revenue stream. Tanzania, on the other hand, has done a reasonable job in fostering competition in the energy market. The largest firm in Tanzania only controls 16 percent of the market and the top four companies together control less than 50 percent of the supply. This is unique for East Africa and stems from the fact that Tanzania has well-crafted regulations that are consistently enforced, which reduces the cost of entry and allow smaller firms to participate in the market.

Uganda's market is also structured differently. It has four large firms that control almost 70 percent of the market, while the remaining 30 percent is divided up among a large number of extremely small companies. In total, Uganda has upwards of 40 companies participating in the market, many more than in the larger markets of Kenya and Tanzania. This is likely due to Uganda's highly liberalized fuel sector, which enables smaller firms to easily participate. At first glance one would assume that having more firms is good for the market because it encourages better access and lower prices. However, Uganda has discovered that having a large number of very small firms can also cause inefficiencies. These companies are often so small that they are unable to achieve economies of scale and experience higher average costs than larger firms. Additionally, regulating many small companies is a significant burden on governments: an overcrowded market may lead to poorer quality products and higher tax evasion, as inspectors are unable to keep a check on so many participants (Bacon and Mattar, 2005).

Finally, Kenya also has a highly concentrated market. The top four oil marketing companies own 80 percent of the market, and the single largest company controls 32 percent of the market. Overall, 25 OMCs operate in Kenya, which is the same number that operate in neighboring Tanzania, despite the fact that Kenya's market is three times larger. The relatively large size of these companies enables them to achieve some economies of scale, but this also comes at a cost. As mentioned previously, small OMCs have been cut out of the market by the larger firms who charge them high wholesale prices. Unable to participate in the Open Tender System, small firms are at the mercy of larger OMCs for their oil supplies. Additionally, the larger OMCs typically underserve less well-developed areas of the country where there are fewer potential profits to be had (Briceño Garmendia, 2011).

2.3 Summary

Through this policy review, many constraints and failures in the fuel supply chain have become evident. In East Africa in general, and Kenya specifically, policies and infrastructure inadequacies have the potential to reduce access and raise costs to end consumers. This is particularly true in rural areas. First, the refining and pipeline infrastructure is inadequate and bottlenecks in the supply chain lead to frequent shortages. Kenya is the only country with an operating refinery, and even then it is grossly uncompetitive based on international standards. Pipelines in both Kenya and Tanzania suffer from chronic underinvestment and poor management. Second, due to price controls, OMCs have little incentive to invest in serving less densely populated rural areas. Price caps restrict OMC's ability to recoup the substantial investments necessary to supply remote regions. While regional pricing ameliorates some of this phenomenon, fixed profit margins continue to incentivize OMCs to focus on densely populated areas to maximize their volume sold. Third, poor road infrastructure and trucking fleets raises transportation costs and increases prices in less accessible areas. The paved road network, while suitable at the regional level, is badly underdeveloped in rural areas. Additionally, road maintenance suffers from underfunding and frequently poor execution of what little rehabilitation does take place. These factors increase the costs of delivering fuel to rural consumers and exacerbate the existing disincentives for OMCs to expand in these areas. Finally, concentrated markets remove competitive pressures on OMCs to improve fuel delivery efficiency. A low level of competition ensures that even very inefficient firms will remain in the market, passing the increased costs of their operations onto consumers.

In the following section, we will estimate the consequences of these supply chain failures directly. Using data collected from rural commercial centers in

Western Kenya, we will attempt isolate the impacts of poor distribution networks on the prices paid for fuel by rural consumers.

CHAPTER 3

RURAL ENERGY USE IN WESTERN KENYA

There exists a large body of work that examines energy access in rural Africa. The majority of these studies focus specifically on households and how they make decisions regarding energy use under personal and environmental constraints. In order to contextualize the challenges facing households, some studies also provide a general overview of energy market imperfections and their implications. Yet other studies take a more macroeconomic view of energy access by examining the energy supply chain as a whole. However, there are no papers – to this author's knowledge – that have formally examined rural commercial markets in Africa, where households themselves purchase fuel. Absent this information, it is difficult to understand exactly how and to what extent these market inefficiencies influence consumers.

The following literature review provides a brief description of the current literature on household energy access in Sub-Saharan Africa. We will highlight the common problems that these studies identify as characterizing fuel distribution systems. In general, these studies fall into two main categories. First, are broad studies that examine rural energy access from a worldwide or regional perspective. Second, are papers that review specific policy interventions related to household energy access. Following this consideration of the relevant literature, the remainder of this chapter reports the results of the author's survey of rural commercial centers in the study region of Western Kenya.

3.1 Studies of Energy Access

Several studies have examined household energy access in Sub-Saharan Africa as part of a worldwide or regional study. Barnes and Floor (1996) were two of the first to examine the issue of fuel access specifically in rural areas in developing countries. They note that rural regions are typically without efficient commercial energy services because it is too costly for retailers to service them. While governments have sought to encourage energy access for poor households through pricing strategies such as price caps, these programs are usually costly and ineffective. Barnes and Floor point out that by reducing oil marketing companies' cash flows, price controls undermine the quality of these companies' services and discourage expansion into rural markets. Additionally, they suggest that poor infrastructure also increases the cost of servicing remote areas, further reducing the incentive to expand into these markets.

Going beyond these observations, Barnes and Floor review several cases of successful and unsuccessful energy programs. Overall, they find that energy expansion programs are most likely to succeed when accompanied by overall income growth and complementary government programs investing in economic infrastructure. Key in their findings is that increased energy access does not substitute for broader rural development programs, but rather supports such efforts. Barnes and Floor identify large "first costs" as a main barrier in deterring demand for modern fuels. Poor households frequently spend more than necessary on energy because they cannot afford the initial cost needed to initiate consumption of a more efficient fuel type. For example, the high cost of acquiring a Liquid

Petroleum Gas (LPG) stove prevents households from using LPG as a source of energy.

In their conclusion, Barnes and Floor recommend a market-based approach to improving rural energy markets in developing countries, and offer two specific suggestions. First, governments should liberalize energy markets to encourage competition and increase access to consumers. Second, governments should avoid the distortions caused by championing technologies or fuels that require extensive subsidies. That is not to say that governments have no role to play in encouraging energy access. Instead, they should encourage market competition, rural infrastructure development, and provide loans to households for in demand energy products.

A more recent look at constraints in Sub-Saharan rural energy markets comes from Schlag and Zuzarte (2008). Their findings largely mirror those of Barnes and Floor from a decade earlier, offering a grim picture of the lack of improvement in energy access since the mid-1990s. Among the similarities, Schlag and Zuzarte find that high up-front costs of adopting modern energy sources is still a prohibitive barrier to most households. Additionally, they see the lack of developed infrastructure, particularly poor roads, as a major impediment to efficient energy distribution to rural areas. In certain areas roads are poor enough that even if distribution companies were to service these regions, transportation costs would be too high to be affordable to consumers.

Schlag and Zuzarte do report several new problems with the energy distribution system. Frist, they point out that poor information exchange between producers and consumers contributes to limiting fuel access. Suppliers lack data on household energy use patterns and so are unable to anticipate demand for modern fuels. Meanwhile, consumers lack information about available modern fuel options and underestimate their associated benefits. A lack of information exchange between the parties causes rural areas to be underserved. Second, Schlag and Zuzarte discuss the importance of social factors in limiting fuel adoption. In most societies, men do not bear the brunt of the negative health and environmental effects stemming from traditional fuel use in the home. Thus, when men are in control of economic decisions, households may not invest in modern energy sources, as they may not highly value the benefits conferred by cleaner fuels. Last, Schlag and Zuzarte note that traditional methods of food preparation often require firewood. These methods are difficult to change even when a switch to a cleaner fuel would be beneficial. Overall, the combination of these three factors causes lower levels of commercial fuel consumption than would otherwise occur.

Other broad studies on rural energy access in developing countries, and Africa in particular include Wolde-Ghiorgis (2002), Spalding-Fecher, et al. (2005), and Kaygusuz (2010). All three articles largely agree with Schlag and Zuzarte on the constraints limiting rural energy consumption. Kaygusuz and Wolde-Ghiorgis pay particular attention to the failures of government policies in promoting rural energy access in Africa. Meanwhile, Spalding-Fecher notes that across Sub-Saharan Africa the private sector cannot often make a profit from rural communities given the poor state of infrastructure and low levels of consumption. All three studies advocate a stronger role for public programs to improve market conditions in developing countries where private companies are failing to invest.

3.1.1 Energy Interventions

The majority of the energy literature pertaining to developing countries, and in particular Sub-Saharan Africa, moves away from broad-based studies and instead evaluates specific policy interventions that seek to promote energy availability for the poor. These studies focus exclusively on households, and generally assume the existence of a poor fuel distribution network as a backdrop to their analysis. In general, little attention is paid to the specific failings of the energy market and any adverse effects the deficiencies of these markets have on households. However, the few studies that do address the fuel supply chain in more detail tend to identify similar constraints to those pointed out in the more general studies referenced above.

One area of particular attention has been government efforts to expand electrical grids into remote regions. Typical of this type of study is a recent report centered on the Kisumu region in Kenya by Abdullah and Markandya (2012). Their study evaluates households' willingness-to-pay to connect to the newly expanded electrical grid. To estimate the potential demand for electrification in the region, the authors discuss the current consumption of commercial fuels. However, little attention is paid to the market in which households purchase these fuels. Instead, the authors broadly describe the market environment, by simply pointing out that there is limited access at reasonable cost. Broad characterizations of this type are common in the literature. For example, in an analogous case study of electrification efforts in Mozambique, Mulder and Tembe (2008) mention that rural areas in this country suffer from very low access to modern energy services. They generally blame poor infrastructure and undeveloped commercial markets, but offer few details.

In a related paper, Spalding-Fecher (2002) examines the impacts of a program to promote electricity efficiency in South Africa on fuel demands other than for electricity. When discussing the impact of the program on energy demand, the authors note that "there is an almost complete lack of adequate, affordable, modern energy services" in their study area. Despite the fact that the poor market condition has a key influence on non-electric fuel demand, there is no exploration of the factors leading to this situation. Other similar articles that discuss electricity expansion in Sub-Saharan Africa include Madubansi (2005), Howells (2006), and Deichmann (2011). In all three, rural energy markets are described as inefficient, but with little elaboration.

Another common area of study is renewable off-grid technologies and their potential to address rural energy needs in Africa. As before, this literature often takes as a given the poor state of the commercial fuel market. However, one study by Amigun, et al. (2008) provides a more in-depth discussion of rural fuel markets than most. The main goal of this article is to evaluate the prospects of commercializing a domestically produced biofuel system in Sub-Saharan Africa. In characterizing the rural energy market, the authors identify four causes of current low levels of commercial fuel use. First, they note a chronic underdevelopment of locally sourced energy resources such as geothermal and hydraulic power. Second, the poorly developed commercial energy supply chain fails to provide adequate supply to meet demand in rural areas. Third, pervasive poverty makes modern energy sources and the technologies that use them unaffordable for many households. Last, the landlocked status of many African countries increases import costs of commercial fuels and drives up retail prices.

A second study focused on renewable energy by Karekezi and Kithyoma (2002) explores the potential for solar photovoltaics (PV) to provide electricity in rural Africa. In their examination of existing fuel markets, the authors point out that while liquid fuels face supply problems in rural areas, they still serve many productive functions in the community. In particular, liquid fuels play a vital role in allowing the operation of small-scale agro-processing and rural transportation. The authors view an opening for PV to serve as a reliable replacement to liquid fuels in serving these important functions. Other studies relating to renewable energy expansion in rural Africa include Karekezi (1994) and Gullberg, et al. (2005). Both of these studies make brief mention of commercial energy markets, and offer similar analysis to that described above.

Overall, the previous literature on rural energy markets provides a general overview of the many challenges that prevent the efficient supply of fuel to rural areas in Africa. These studies agree that uncompetitive markets, counter-productive government policies, and inadequate infrastructure are the main problems facing the industry. Nevertheless, little has been done to examine the actual dynamics of rural commercial centers that sell fuel to consumers. In particular, research to date has not gathered any data from existing fuel markets in order to quantify the impacts of these commonly identified market failures. The survey of rural commercial centers in Western Kenya described below was conducted to address this gap in the literature. By collecting detailed data from market participants in rural commercial centers in Kenya, we hope to shed light on the specific channels through which these markets operate, identify key market failures, and discuss the magnitude of their impacts on consumers.

3.2 Rural Energy Survey

Data on energy use in rural commercial centers and in transportation were collected from May to August 2012 in targeted rural areas surrounding the city of Kisumu in Western Kenya. The objective of the survey was to gather detailed information regarding fuel sales and consumption in commercial centers that service rural communities. The survey was conducted in five ten-by-ten kilometer (100 km^2) “blocks” located in the Western, Nyanza, and Rift Valley provinces. The five blocks are referred to as Upper-Yala, Mid-Yala, Lower-Yala, Mid-Nyando, and Lower-Nyando after their locations in the Yala and Nyando river basins (see green shaded areas in Figure 3.1 below). The five blocks were chosen as the data collection site for several reasons. First, these areas formed parts of the original geographic coverage of the Western Kenya Integrated Ecosystem Management Project (WKIEMP), implemented between 2005-2010 by the Kenya Agricultural Research Institute (KARI) and the World Agroforestry Center (ICRAF). This previous project, plus other prior studies by ICRAF and other Cornell University researchers offered the opportunity to supplement our findings with those of previous research. Second, the five blocks were created along two of the major rivers (the Yala and Nyando rivers) that flow from the Western Kenya highlands towards Lake Victoria, crossing various agro-ecological zones. This wide geographic range allowed the survey to gather data from five heterogeneous climates and associated economic systems. Finally, the Western Kenya highlands are one of the poorest (over half of the population lives below the rural poverty line) and most densely populated areas of the country (World Resources Institute, 2007). This allows our survey to gain a better understanding of how energy markets impact the rural poor.

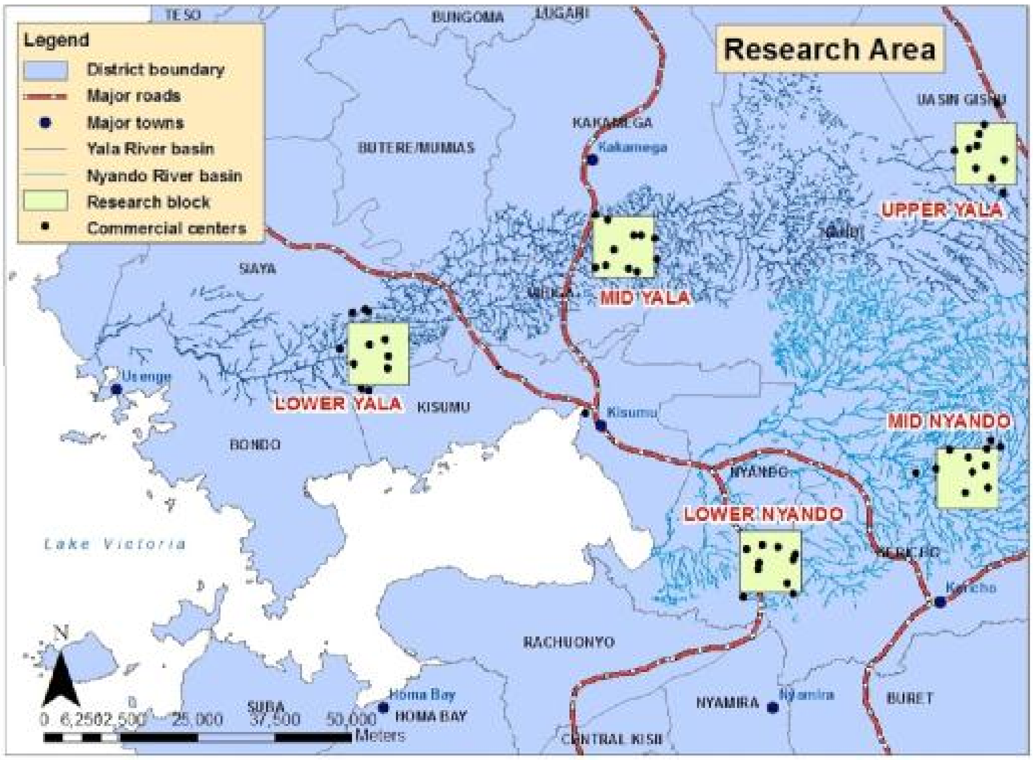

Figure 3.1: Map of Research Area

Our survey identified 56 commercial centers within the study area; these are indicated as black circles in Figure 3.1. Note that some circles appear to be slightly outside the survey areas due to inaccuracies in GPS location recording. A commercial center was defined as any group of two or more permanent structures whose collective purpose was primarily commercial. The centers ranged greatly in size from only two businesses up to 222 businesses. Many centers were associated with nearby villages that they served, but several also stood independently and catered to disperse populations from a wider area. The commercial centers were evenly split between the five blocks, with 11 centers located within the Lower-Yala, Mid-Yala, Upper-Yala, and Lower-Nyando blocks while 12 centers were found within the Mid-Nyando block. Of the 56 commercial centers, 50 were connected with the electrical grid, although of these, three had no actual power at the time of the visit.

The survey team conducted interviews at each center during business hours, ranging between 10:00 am and 4:00 pm. Data was collected from every shop (only permanent structures were approached) that was open at the time of the visit. The owner of the shop was administered the questionnaire unless he/she was unavailable, in which case whoever was running the store at that time was asked the questions in their stead. Answers to questions related to the types of energy used and sold were recorded for each respondent with a more detailed survey conducted for businesses that sold energy. Additionally, businesses that used petrol, diesel, LPG, kerosene were asked to answer additional questions pertaining to their levels of consumption and sources for each fuel. Only five kerosene users were asked additional questions in each center in order to keep the time spent in one commercial center to a manageable level. In total, 1,438 businesses were recorded in the survey. Of these, 407 were asked to complete the more detailed survey either for fuel sellers, fuel users, or both. Refusal rates by businesses asked to complete the detailed survey were very low, nearly zero, within the sample area. To clarify these distinctions, Table 3.1 reports the total number of respondents interviewed in each category and the information that was elicited from each group.

Table 3.1: Survey Overview

	Number of Observations	Definition of Group	Data Collected
All Businesses	1,438	Any business that was in operation at the time of the survey.	List of all energy sources that were used or sold by that business.
-Fuel Sellers	131	Any business that sold any fuel type in the commercial center.	Detailed survey regarding type and quantity of fuel *sold*.
-Fuel Users*	323	Any business that used *liquid* fuel in their operations.	Detailed survey regarding type and quantity of fuel *used*.
Transporters			
-Matatus	77	Any *matatu* driver that serviced the survey area and was available at time of survey.	Detailed survey regarding quantity and price of fuel *used*.
-Boda-bodas	296	Any *boda-boda* driver that serviced a commercial center and was available at time of survey.	Detailed survey regarding quantity and price of fuel *used*.

Note: Fuel Sellers and Fuel Users are not mutually exclusive categories.
**Only five kerosene users in each commercial center were given the fuel user survey.*

The detailed questionnaire administered to business owners contained four parts. The first part collected basic identification information about business type, years in operation, and ownership. Second, each business was asked questions about which specific fuels they sold and used. Third, for each fuel type, information was gathered on the quantity and price of the fuel that was sold or used. Lastly, the business was asked if they had any difficulty in obtaining the fuel. In the event that a store sold or used multiple types of fuel, the survey was repeated for each fuel type in its entirety.

In addition to businesses, transporters who served each commercial center were also interviewed. These transporters were surveyed in two stages. The first class of transporters was "*boda-boda*" drivers. "*Boda-boda*" is the local term for motorcycle taxis that are commonly used for public transportation throughout Kenya. *Boda-boda* drivers were interviewed at each commercial center while the business survey was being conducted, with up to ten *boda-boda* drivers interviewed at each center. An attempt was made to interview any driver who was currently stopped at the center upon arrival or any driver that arrived during the survey team's stay. A minimum of one hour was devoted to waiting for new drivers to arrive if the maximum of ten drivers had not already been reached.

The second class of transporters was "*matatu*" drivers. "*Matatu*" is the local term for small 6 or 10 seat public buses that are frequently used for long transport between cities and larger towns throughout Kenya. *Matatu* drivers were interviewed after the completion of the commercial center survey. Based on conversations with members of the community, thirteen *matatu* routes were identified that served the five blocks of interest. Like the *boda-boda* survey, up to ten *matatu* drivers were interviewed from each of the thirteen routes. Interviews were conducted at the terminus of each route in order to allow the drivers enough time to complete the survey. As a result, most interviews were actually conducted outside the blocks and commercial centers themselves.

In total, the transporters' questionnaire was administered to 296 *boda-boda* drivers and 77 *matatu* drivers. Refusal rates by transporters were also very low, but higher than among businesses, with approximately 5 percent of transporters refusing to take part in the survey. The survey contained four different sections. The first section covered fuel purchasing behavior. More specifically, drivers were asked about the amount of fuel they purchased each day, where they purchased their fuel, how often they refueled, and the price they paid per liter. The second section dealt with pricing schemes and the levels of fares that transporters charged their customers. The third section asked drivers about their perceptions of the market – how many other *boda-bodas* or *matatus* they estimated were operating on the route. Where possible, this information was verified using official lists from local transporter organizations detailing the number of drivers operating between commercial centers or on a specific route. Finally, the last section covered demographic information.

3.3 Fuel Sellers

In our sample of 1,438 businesses, 131 of them sold some sort of fuel. The demographic information from these 131 business owners is typical of the sample population in general. Within the subset, 73 of the business owners were male (56 percent), and the median age was thirty years old but ranged from 18 to 85. There did not appear to be any division between age groups or gender on what type of store is operated. The one exception was gas stations where men operated seven out of the eight. Education levels were relatively high with 85 percent of the sample having completed primary school, 46 percent secondary school, and eight percent with at least some college level education.

The types of businesses in the sub-sample were quite heterogeneous, ranging from gas stations marketing large quantities of petrol and diesel to individual businessmen selling small quantities of kerosene. Table 3.2 summarizes these fuel sellers by sorting businesses into four store categories and by the fuel type they sell.

Table 3.2: Business Type by Fuel Sold*

	Individual Seller	Retail Store	Gas Station	Other
Petrol	6 (33%)	3 (17%)	7 (39%)	2 (11%)
Diesel	7 (37%)	4 (21%)	7 (37%)	1 (5%)
Kerosene	21 (20%)	69 (66%)	8 (8%)	6 (6%)
LPG	2 (25%)	2 (25%)	3 (38%)	1 (13%)
Charcoal	12 (55%)	8 (36%)	0 (0%)	2 (9%)
Firewood	1 (50%)	1 (50%)	0 (0%)	0 (0%)
Overall	37 (28%)	77 (59%)	8 (6%)	9 (7%)

**The total percent of businesses in each category is reported in parentheses.*
Note: Some stores sell multiple types of fuel and are counted in multiple rows.

In our classification, individual sellers are businesses that primarily sell fuel. In contrast, retail stores are businesses that sell fuel as one of many types of other household goods. Gas stations are classified as any business that sold fuel primarily through a metered gas pump. Stores that fall under the "Other" classification are businesses such as hotels that also sold fuel for extra income.

Table 3.2 above shows how store type varies greatly based on the type of fuel. Petrol, diesel, and LPG are distributed disproportionately by gas stations while retail stores and individual sellers are the primary distributors of kerosene. Meanwhile, charcoal and firewood are only available from smaller businesses.

3.3.1 Quantity of Fuel Sold

Having described the basic make-up of the businesses in the "fuel seller" category, we now move on to examine how much fuel these stores are selling within the blocks. Looking first at the percentage of stores selling each type of fuel (see Figure 3.2 below), it appears that kerosene dominates the market, as it is by far the most commonly sold fuel.

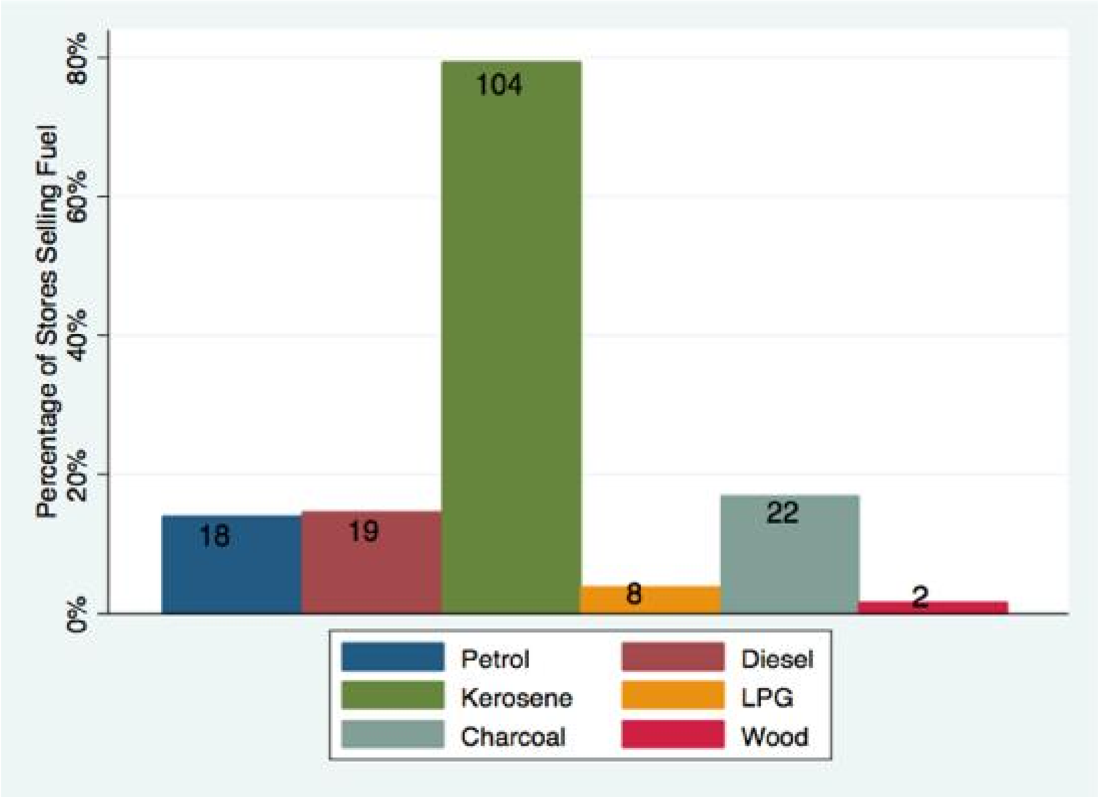

Figure 3.2: Number and Percentage of Stores Selling Each Fuel
Note: Stores selling multiple fuel types are counted for each fuel respectively.

Nearly 80 percent of the businesses surveyed sold kerosene. Overall, the total numbers of stores selling the different fuel types were as follows: 18 petrol sellers, 19 diesel sellers, 104 kerosene sellers, eight LPG sellers, 22 charcoal sellers, and two firewood sellers. Note that some stores, such as gas stations, sold many fuel types and are counted in multiple categories. The bar graph below gives a visual representation of these numbers. The height of the bars represent the percentage of stores that sold each fuel, while the number on each bar is the total number of stores in that category.

As shown in the Table 3.2, kerosene is often sold by general stores and is marketed alongside other household goods, while other fuels are sold more exclusively by gas stations or dedicated individual sellers. This suggests that kerosene is widely used in rural communities and may be thought of a basic necessity for many households and businesses.

One explanation for kerosene's wide usage is the relative lack of access to electricity in rural areas. While 48 of the 56 commercial centers had nominal access to the grid, in practice many businesses and almost all households still lack a electrical connection. Absent this more efficient energy source, households and businesses continue to turn to kerosene as their primary source for lighting and occasionally for cooking.

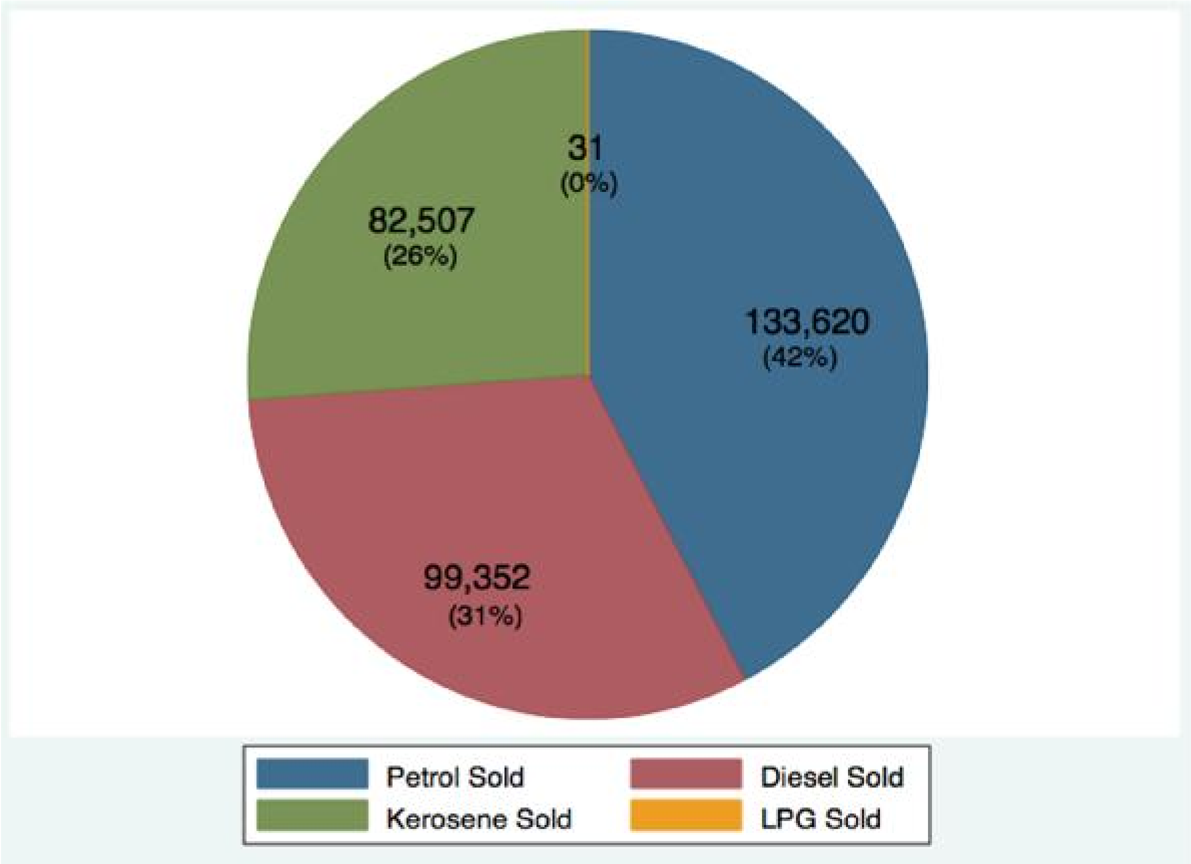

Figure 3.3: Amount Sold per Month
Note: Amount sold in liters. Liters of LPG were calculated by converting kilograms sold using the density of LPG of .566 kg/L.

While kerosene appears to be the dominant fuel type based on the number of stores that sell it, the quantity of fuel sold by volume tells a different story. As shown in the figure above, in terms of volume sold, petrol (42 percent) is the dominant fuel in the marketplace. Petrol is followed by diesel (31 percent), and kerosene (26 percent), each making up more than a quarter of the market respectively. LPG, charcoal, and firewood make up a negligible percentage of the volume sold (less than one percent collectively). These monthly sale volumes were calculated by converting reported sales data into liters (from other units of measurement) and normalizing to a month-long time span. Figure 3.4 examines the differences in sales volume among the five blocks.

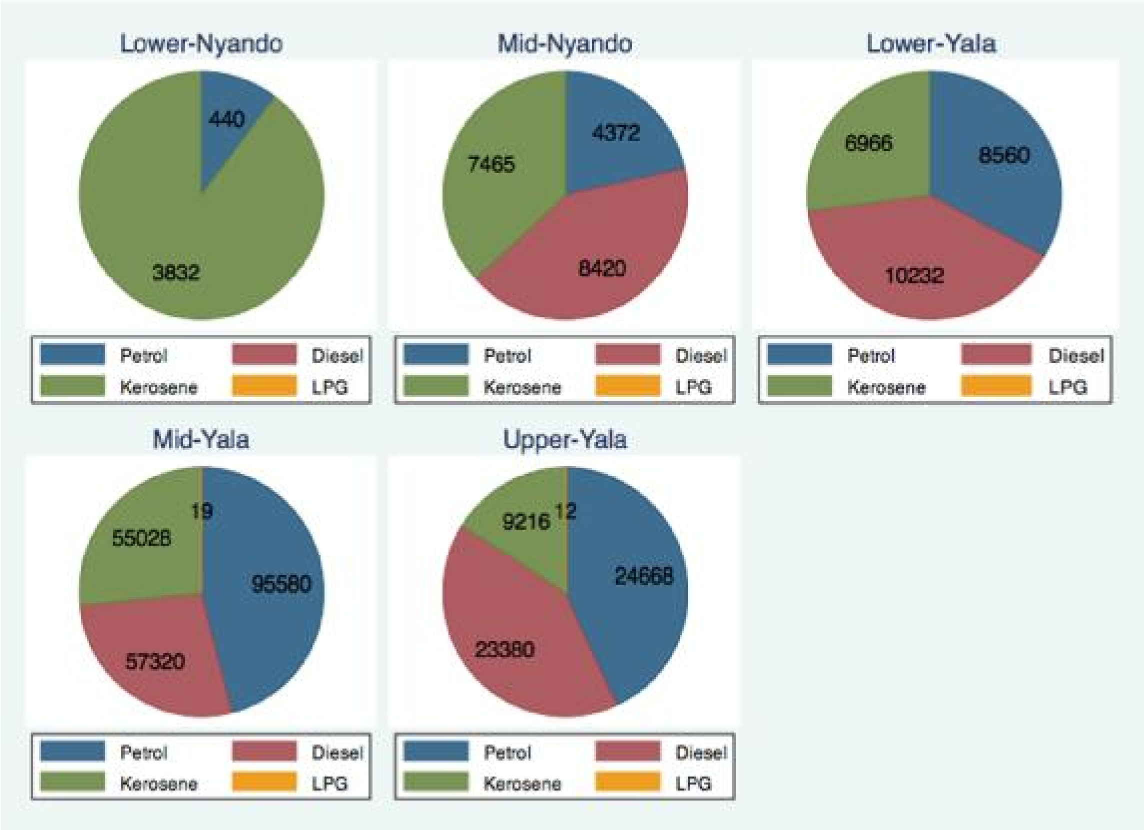

Figure 3.4: Amount Sold per Month

The five blocks are heterogeneous in both the amount and type of fuel that is sold in each. As shown in Figure 3.4, Lower-Nyando sells by far the least about of fuel per month. This may be due to the smaller population size in this block, as there are no large commercial centers or gas stations within the ten by ten km perimeter. Individual sellers account for the entirety of what little petrol sales exist in this block. While diesel is almost certainly consumed by some businesses and transporters operating within Lower-Nyando, it is not available for sale and so is excluded from the chart. Both Mid-Nyando and Lower-Yala sell moderate amounts of fuel, but they are both well below the quantity sold in either Mid or Upper-Yala. These differences may again be explained by the relative size of the population and importance of the commercial centers in each block. Furthermore, Upper-Yala is home to "Moi University", a large regional university, which attracts relatively wealthy students (which may also explain increased LPG usage) and more vehicle traffic. However, it is also possible that some of the disparities in fuel sales also reflect failures in fuel distribution networks to offer adequate sources of fuel in certain blocks.

The data illustrate that having more stores selling a particular fuel type does not necessarily mean that there is a greater quantity of that fuel being sold. On the one hand, there exist a few businesses that sell large volumes of petrol and diesel. On the other hand, there are many more businesses that sell small quantities of kerosene. We hypothesize that the reason for this disparity is that petrol and diesel are generally purchased for cars, trucks and other machinery that require large amounts of fuel. Conversely, kerosene is only required in small amounts by households that use it for lighting and cooking. The following figure addresses this idea by revealing what types of customers are purchasing each fuel.

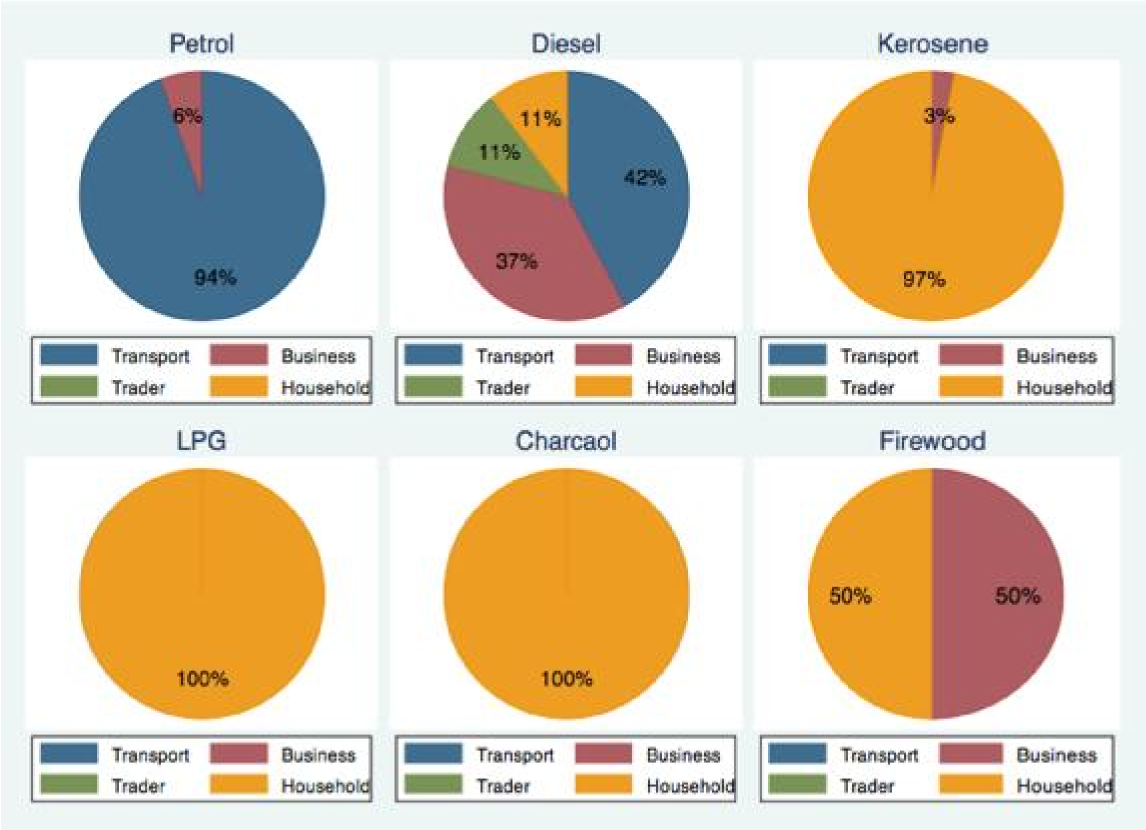

Figure 3.5: Main Customers for Each Fuel Type
Note: Traders are defined as other energy sellers who purchase for resale.

The charts in Figure 3.5 illustrate the responses of fuel sellers to the question "Who are your main customers?" for each and every fuel type they sell. The results demonstrate how the market for each fuel varies greatly. Petrol is sold almost exclusively to transporters such as *boda-bodas* (motorcycle taxis), *matatus* (public buses), or private vehicles. Diesel is used more diversely, as it is sold to transporters, local businesses, households and other energy traders (presumably for resale in other areas). As previously discussed, kerosene sales are dominated by households, which use the fuel for lighting and cooking. LPG and charcoal are also used almost entirely by households, while both business and households use firewood (although as N=2 for firewood sellers, this is merely illustrative). These results confirm our previous hypothesis that differences in sales volumes between fuel types are driven by the type of customers for each fuel, rather than the number of stores that offer them.

3.3.2 Fuel Prices

Figure 3.6 below shows the mean price of a standard unit of fuel. A standard unit is a liter for liquid fuels and a "bundle" in the case of charcoal and firewood.

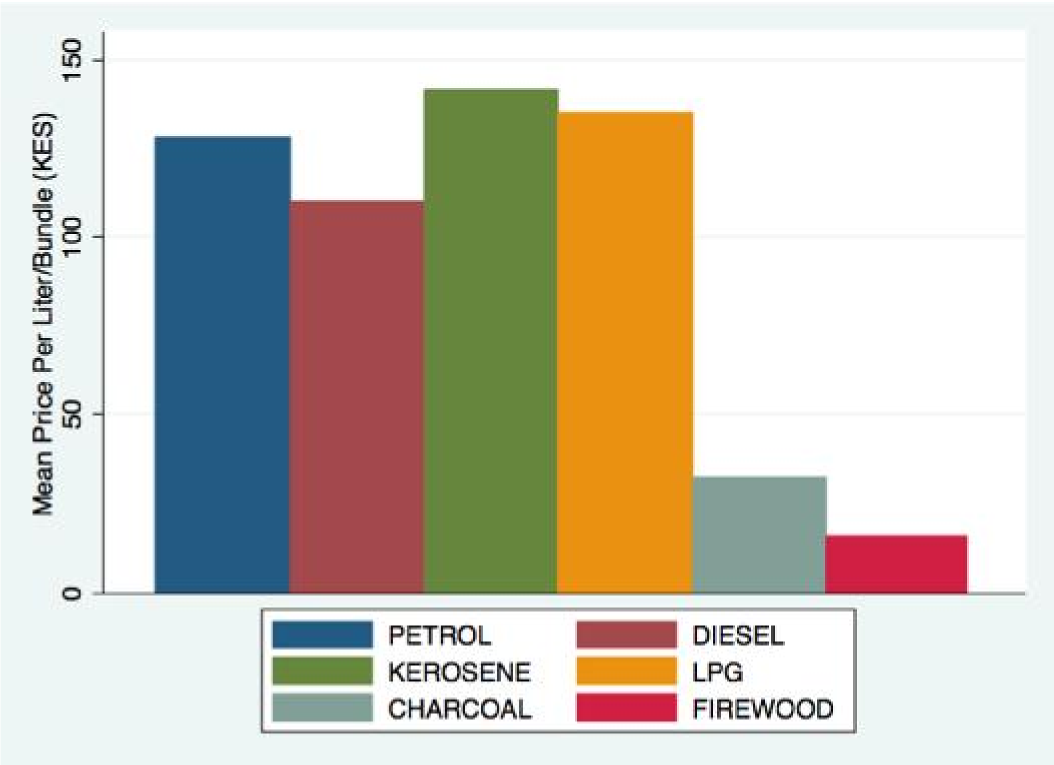

Figure 3.6: Mean Prices of Fuels

Among the liquid fuels, kerosene is the most expensive followed by LPG, petrol, and finally diesel. Kerosene sells at an average price of 141 Kenyan Schillings[11] (KES)

[11] This is equivalent $1.72 (US), at exchange rate as of May 1, 2012.

per liter. LPG is slightly less costly at 135 KES per liter[12]. The cheapest liquid fuels are petrol, sold for 128 KES per liter, and diesel, which costs 110 KES per liter. While these differences in prices might seem relatively small, given the low incomes of most rural households these differences can be quite significant

Charcoal and firewood are significantly cheaper than the liquid fuels, selling at 32 KES and 16 KES per bundle, respectively. While these two energy sources are appealing in terms their price, they have the disadvantage of yielding much lower energy outputs. As a result it becomes difficult to compare these energy types based on prices alone.

It should be noted that the prices we are referring to represent the average prices charged per unit. This was deemed an appropriate measure because the majority of businesses list their prices in terms of the standard unit. However it is worth mentioning that in the case of kerosene this average measure masks a great deal of variation in prices based on the unit of kerosene sold. The impact of this price variation will be explored later.

Additionally, the differences in price per energy output of our different fuel types should be mentioned. While liquid fuels may be more expensive on a volume basis they may actually represent better value based on the amount of energy they contain. For example, the energy density of LPG is 27.7 MJ/L (mega-joules per liter) compared to 37.3 MJ/L for diesel (Australian Institute of Energy, 2013). However, using energy density of each fuel may be misleading as the actual *useful* energy that

[12] Liters of LPG were calculated by converting the 6 kg and 13 kg canisters typically sold into their liter equivalents (using .566kg/L).

is delivered and hence fuel efficiency depends in significant part on what type of technology is employed by the consumer. To illustrate this point, the energy output delivered by burning fuelwood in an open pit is approximately 3 MJ/kg (mega-joules per kilogram), which can be improved to 5 MJ/kg by burning fuelwood in a efficient three-stone stove. Meanwhile, a typical kerosene stove delivers 12 MJ/kg, on average, compared to 27 MJ/kg delivered by an LPG stove, despite kerosene having a higher energy density (Barnes and Floor, 1996; Kaygusuz, 2011). Because the efficiency of each fuel type is so highly dependent on the technology used by the consumer, our analysis here deals strictly with prices on a per liter basis.

3.3.3 Sources of Fuel

Nearly all the businesses sampled in the survey sell their fuels directly to consumers and are at the end of a complex fuel distribution network. There are nonetheless a few businesses that sell to other businesses for resale (primarily gas stations). These retailers have to purchase their fuel from an intermediary, such as distribution depots in Kisumu, Kakamega or Kericho, and then transport the product back to their businesses. The gas stations, for their part, are often owned by larger fuel distributors and do not need to purchase their fuel from third parties. Overall, 92 percent of fuel sellers indicated that they purchased their fuel from outside their (respective) commercial center. Figure 3.7 below shows the average distance fuel sellers must travel in order to purchase the product. It is worth highlighting that in a few cases the business owners do not travel themselves but rather have the fuel delivered.

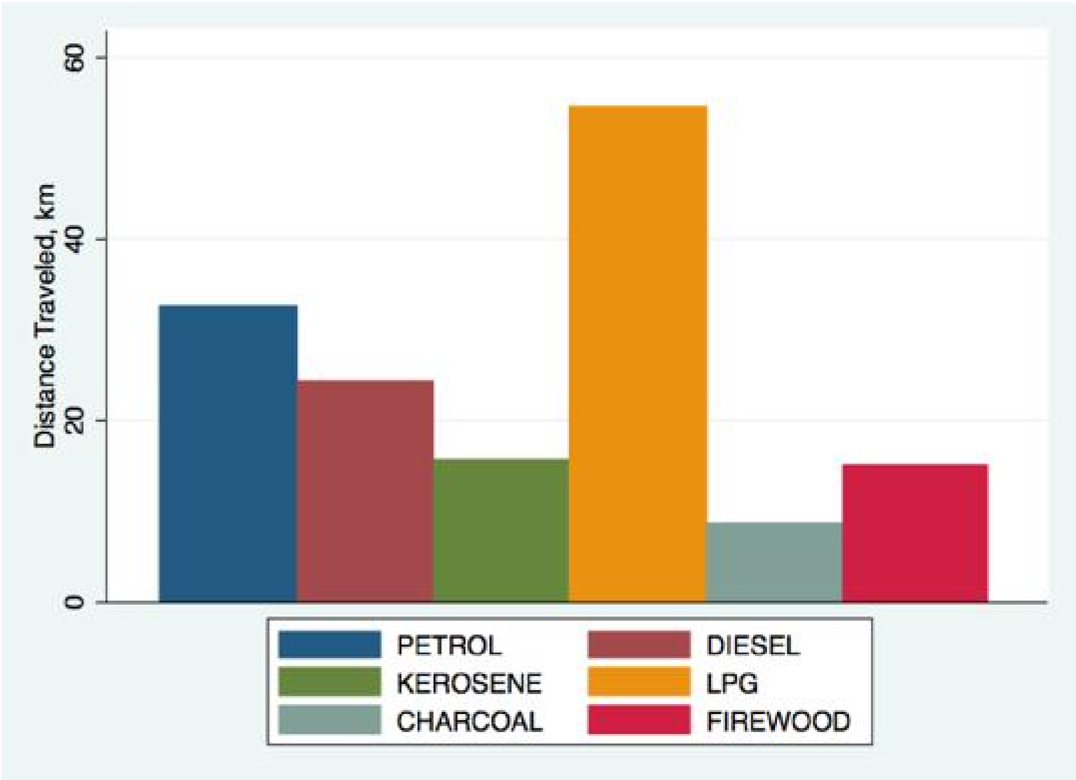

Figure 3.7: Mean Distance to Fuel Source

Figure 3.7 shows that sellers must travel the longest distances in order to purchase LPG. On average, LPG is sourced 54.6 kilometers away from the business location. Petrol comes in a distant second, being sourced an average 32.5 km from sellers' businesses. LPG and petrol are followed by diesel, which is sourced from 24.3 km away, and kerosene, which is purchased from 15.9 km away. Finally, sellers of charcoal and firewood travel an average distance of 8.8 km and 15.0 km respectively.

There are three features to highlight about the results regarding distances travelled. First, LPG is sourced from the furthest away in large part because it is not commonly used in rural areas. Almost all of the rural sellers had to travel to Kisumu (30-100km away) in order to purchase it. Moreover, there are no secondary distributors outside the main cities and the secondary distribution channels for LPG have remained underdeveloped. Second, among the liquid fuels, kerosene sellers travel the shortest distance to purchase fuel. This indicates that kerosene either has a more developed wholesale network or that kerosene sellers are more likely to purchase it from other nearby energy dealers for resale. Finally, the distribution networks for charcoal and firewood cannot be compared with those for the liquid fuels because these fuels are produced and gathered locally. In contrast to liquid fuels, fully 40 percent of charcoal and 50 percent of firewood sellers indicated that they purchased their charcoal within the commercial center or from a passerby (often a bicycle salesman).

3.3.4 Fuel Shortages

In addition to traveling relatively long distances to purchase fuel, sellers were often unable to purchase fuel at all. Approximately 59 percent of the sample of fuel sellers reported experiencing a fuel shortage in the past year (defined as any time the seller attempted to buy but was unable to obtain fuel stocks for resale). Shortages were reported across all fuel types, as indicated in Table 3.3

Table 3.3: Fuel Shortages by Fuel Type

Fuel Type	Percent of Sellers Reporting Shortage in Past Year
Petrol	67%
Diesel	26%
Kerosene	59%
LPG	75%
Charcoal	73%
Firewood	50%

When asked to identify the reason for the fuel shortages experienced, responses varied greatly. The most common was simply that the fuel was unavailable from their normal supplier (60 percent). However, some respondents were able to identify specific failures in the upstream distribution network that were the cause of the shortage. Figure 3.8 shows the incidence of responses by fuel type.

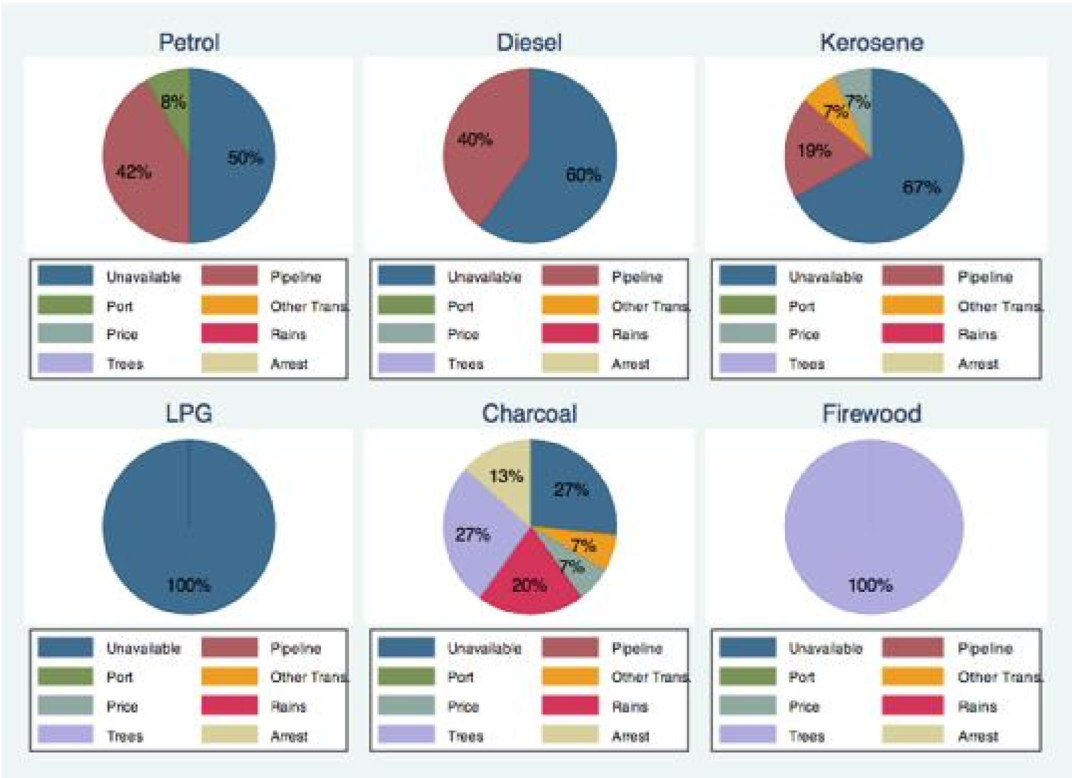

Figure 3.8: Reasons for Fuel Shortage

Looking first at the liquid fuels, it is clear that the majority of sellers were uncertain of the causes of the fuel shortages. Among respondents who were able to identify a specific reason, pipeline problems was the most common answer. The pipeline in Kenya runs from Mombasa to Nairobi and is an important first step in the delivery system for liquid fuel from the port to the interior of the country. The pipeline problems referenced by the energy sellers most likely refer to a pipeline explosion that occurred in a Nairobi slum in September of 2011 (*Huffington Post*, 2011). Additionally, few petrol sellers cited problems at the port (Mombasa) as contributing to a fuel shortage. Meanwhile, some kerosene sellers reported transportation problems such as "bad roads" preventing fuel delivery or simply being unable to afford the price of kerosene.

Charcoal and firewood sellers give much different reasons for supply problems than liquid fuel sellers. As show in Figure 3.8, their supplies suffer from several unique constraints. First, the rainy season limits the production of charcoal as dry wood becomes difficult to collect and char. Second, general deforestation in the survey area limits the supply of both charcoal and firewood. Last, making charcoal is technically illegal in Kenya and periodic crackdowns by police can sometimes disrupt supply. However, while it is illegal, charcoal production remains common. Charcoal sellers reported that enforcement of the production ban is usually lax and is often only pursued by police seeking a bribe.

3.3.5 Seasonality of Demand

Previously, we discussed the different primary uses for each fuel type within our surveyed communities. As a consequence of these differences, each fuel also has its own unique peak sales period throughout the year. To capture these cycles, the survey instrument asked each seller which months they sold more fuel than average. Figure 3.9 below presents the percentage of stores reporting higher than average sales for their own store by month for each fuel type (firewood is excluded due to the small sample size). The twelve months are presented in order from January to December and show the percentage of stores indicating higher than average sales relative to their own store.

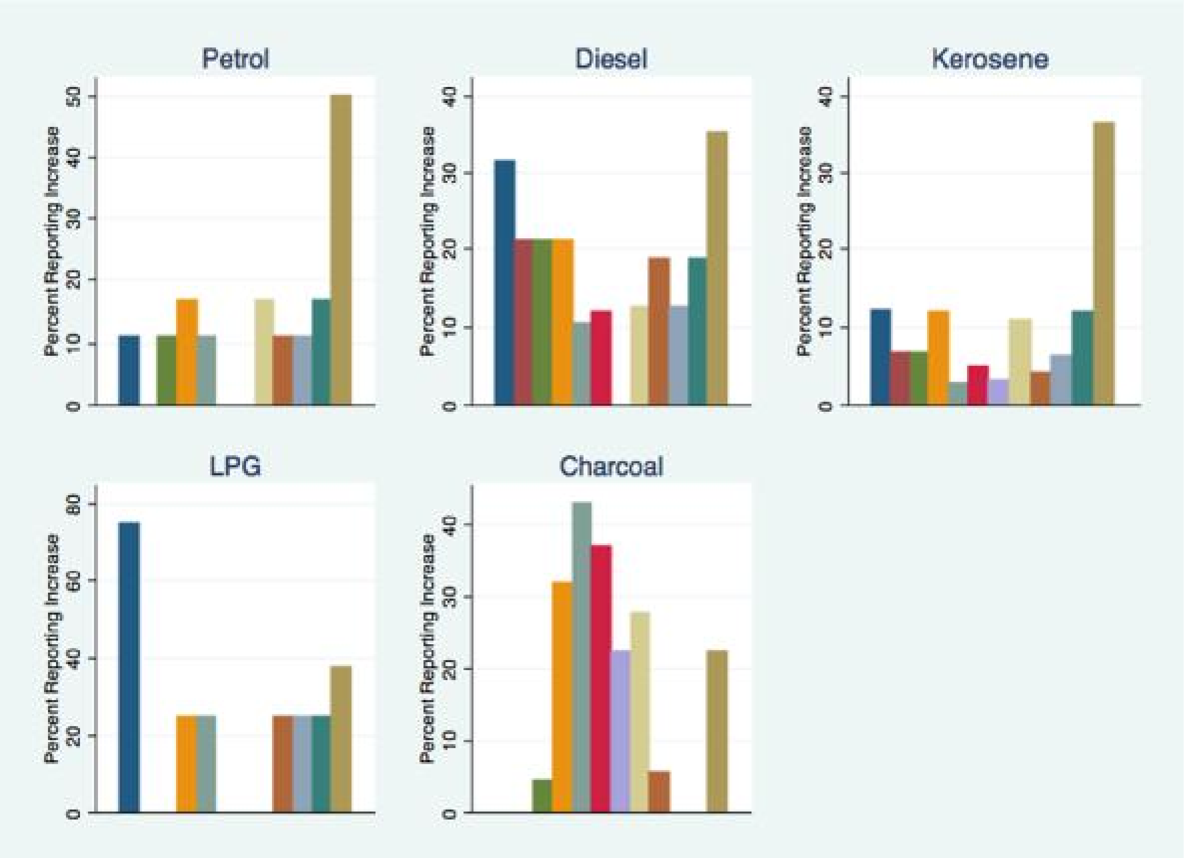

Figure 3.9: Peak Sales by Month

It is worth mentioning that “higher than average” should instead be phrased as “higher than annual average”. Additionally, this is a subjective question and as a consequence produced some unusual answers. A small percentage of energy sellers reported that their store experienced above average sales nearly every month of the year (this might be considered a demonstration of the "Lake Wobegon" effect[13]). Similarly, several stores reported no peak season at all. For this reason, in Figure 3.9, if ten percent of energy sellers reported "above average" sales, this should not be considered to be a peak season for that fuel type. Rather, in order to consider a month a peak sales period, we use a rough benchmark of 20 percent of energy sellers reporting higher than average sales.

Examining Figure 3.9 above we can identify a few interesting features. First, there is an increase in fuel sales in the month of December across all fuels. Second, some of the liquid fuels appear to have peaks at the beginning and end of the year while charcoal shows the reverse pattern. Last, nearly every seller (80 percent) of LPG reported an increase in sales during January. In order to explain these patterns, the survey asked each energy seller the reasons for their above average sales. Respondents were asked for the "most common" reason overall, so the responses are independent of individual months. Nevertheless, by aggregating responses for each fuel type, we can understand what may be some of the driving factors behind fuel shortages. Figure 3.10 reports responses for increased fuel sales for each fuel type separately.

[13] Garrison Keilor's "Lake Wobegon" effect refers to the claim that in the mythical Lake Wobegon, Minnesota, "all children are above average." The same claim can be extended, for example, to the phenomenon that nearly all individuals claim to be above average for some skills such as driving or comedic ability.

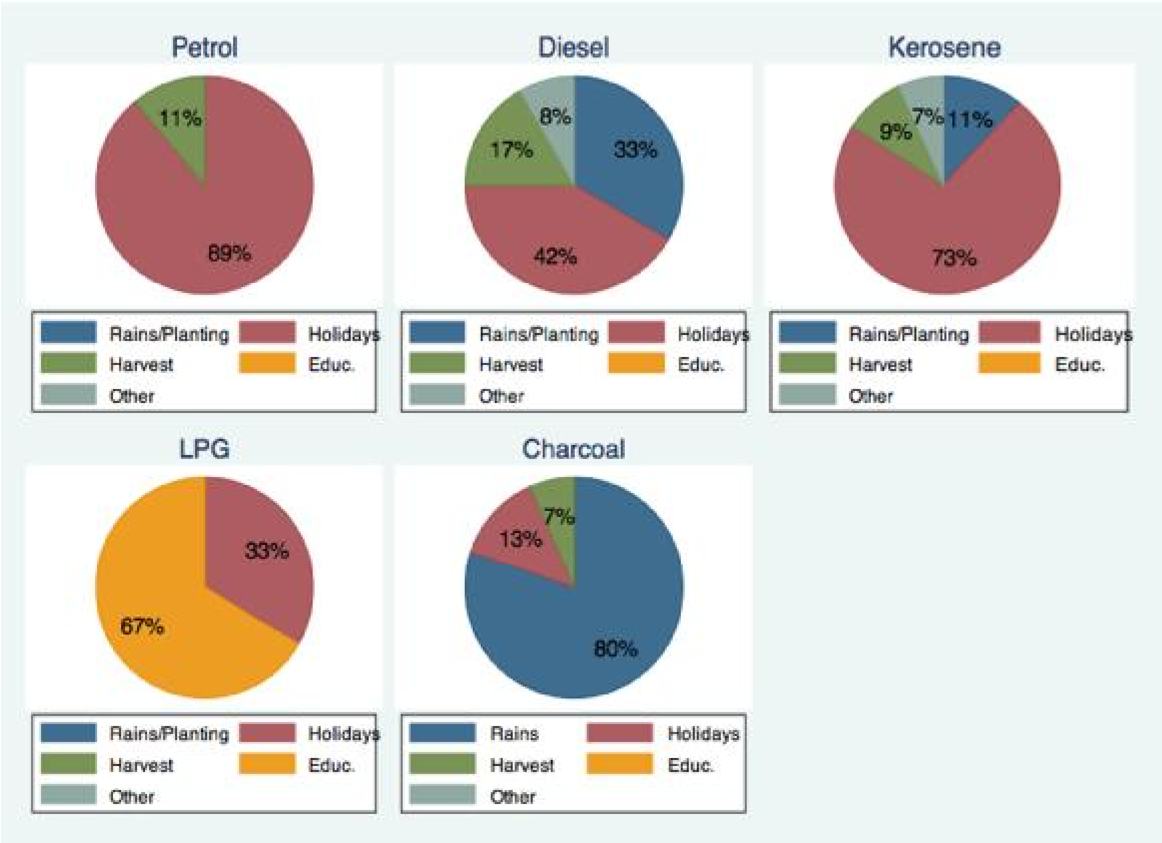

Figure 3.10: Reason for Increased Sales by Fuel Type

The category "Rains/Planting" refers to either to the rainy season, which lasts approximately from March to June, or to the planting season, which coincides with the start of the rainy season in March and April. "Holidays" refer to the return of family members to the village during the December Christmas season. "Harvest" refers to the harvest season that occurs at different times throughout the year depending on the microclimate and the crops being harvested in the area. "Educ." refers to the return of students to university after the December holiday.

The dominant reason given for peak sales of both petrol and kerosene (and the most important reason overall) are the holidays. As family members return home in December they increase the use of petrol through transport and the use of kerosene by households for lighting and cooking. Diesel fuel is more evenly split between reasons for increased use. Holidays remain an important reason for above average sales due to the more frequent use of diesel-burning *matatus*, but both the rainy season and harvest are important factors. This result may be explained by the fact that most large farm equipment is run on diesel. As a result, diesel sales are likely more connected to the local agriculture cycle than are sales of other fuels, exhibiting an increase in demand during planting and harvest. Indeed, if we examine the peak sales graph for diesel in Figure 3.9, there appears to be a relatively steady level of reported "above average" sales throughout the year rather than one large peak in December. This indicates that diesel sellers in different agro-ecological zones may face higher demands for diesel fuel at different times based on the particulars of their local farming systems.

LPG sales appear highly tied to the education system as the return of students to Moi University (in Upper-Yala), which appears to drive the increase in January. Relatively wealthy students are more likely to be able to afford LPG as a fuel and are likely to buy a new canister of fuel upon their return to campus. Again, charcoal stands out from the liquid fuels, in that the dominant time for increased sales is the rainy season. During the rains it may be harder for households to gather their own firewood or produce their own charcoal, driving families to seek out more from the marketplace.

In this section we have discussed the survey data from our sample area reflecting the responses of fuel sellers. By looking the number of stores, amount of fuel sold, sources of fuel, fuel shortages, and the seasonality of demand we have attempted to highlight important aspects of the amount and nature of fuel sales within the survey area. From here, we will move on to examine the data gathered about fuel users within the commercial centers.

3.4 Fuel Users

The energy user data is less complete than the data collected from energy sellers. As mentioned before, all sellers and users of energy were recorded in the survey. However, while every energy seller encountered in survey area was given a detailed survey, due to time constraints only a sub-sample of fuel users were given the same. Of the 407 businesses given a detailed survey, 323 of them used some liquid fuel in their operation (note that 47 businesses were recorded both as an energy seller and energy user, see Table 3.1). Survey data on energy users were collected at the same time and from the same survey area as that for the energy sellers. However, unlike the energy sellers, the total sample of 323 energy users represents only twenty-two percent of the total population of 1,438 total businesses that were recorded as using fuel throughout the survey area. Consequently, while we can make inferences about fuel use behavior we are unable to estimate total fuel consumption as we did with energy sellers.

Fuel users were defined as any business that consumed some energy source in their operation. These sources were much more varied than the fuels sold, ranging from use of diesel to solar panels. Demographically, fuel users are very similar to the fuel sellers. The median age of business owners is 32 years, ranging from 17-85 years, and the sample is 59 percent male. Educational achievement is also similar to fuel sellers, with 82 percent of the sample respondents having completed primary school, 43 percent secondary school, and 10 percent having completed some college education.

3.4.1 Fuel Use by Type

For fuel users, our detailed survey only captured a subsample of fuel used in the survey area. For this reason, extrapolated estimates of total volume used would not be informative. However, we can study the frequency of fuel use in commercial centers using our full sample of 1,438 businesses, which includes *all* energy sources, not just liquid fuels. The graphs below show the percent of stores using each type of fuel. As we are concerned with fuel bought and sold in the market, electricity users have been left out of the analysis.

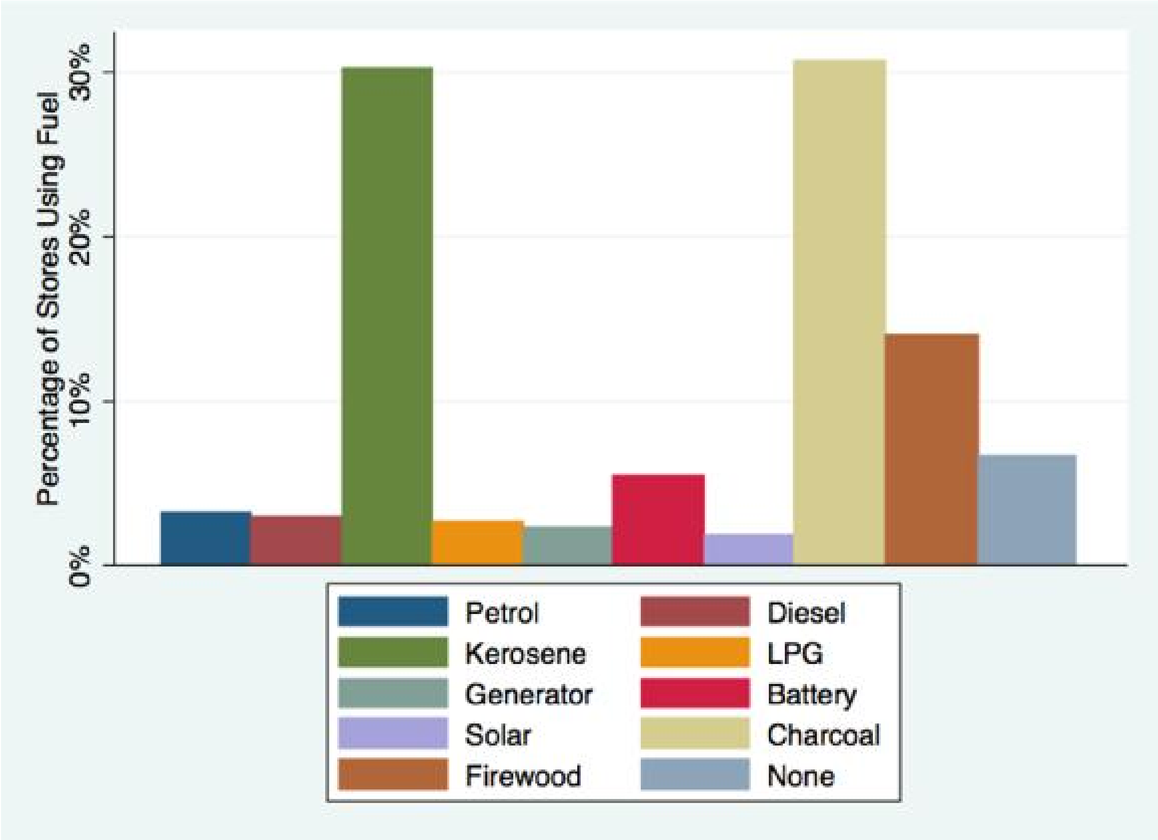

Figure 3.11: Percent of Businesses Using Each Fuel Type
Note: Stores Using Multiple Fuels are counted for each fuel respectively

Figure 3.11 above clearly shows that a wider variety of fuels are used by business as compared to the number of fuels sold within the block. Kerosene and charcoal (30 percent each), followed by firewood, are the dominant fuels consumed by businesses. The remainder of users employ a variety of energy sources, including independent generators and solar panels. Additionally, seven percent of the sample used no source of energy at all.

3.4.2 Liquid Fuels Used by Business Type

Reducing our analysis to the 323 businesses that used liquid fuel (for whom we have more detailed information), we can examine which types of businesses are using each fuel type. As the sample only contains businesses that use these fuels, we are in effect parsing the different uses of fuels that were previous grouped together in the sellers' analysis. Within this sub-sample, 13 percent of the businesses (N=46) used petrol, 12 percent used diesel (N=41), 65 percent used kerosene (N=224), and 11 percent used LPG (N=37).

In order to simplify the analysis, each business was placed into one of five categories. "Posho Mills" are businesses that mill grains for the local community. Posho mills use energy intensive machinery to grind maize into flour for the local community. "Services" include businesses such as barbers, health clinics, printers, and phone charging stations. "Hotels/bars" include also restaurants and entertainment businesses. "Retail stores" encompass any business selling basic consumer goods. Finally, "Mechanics/carpenters" include car garages and furniture makers, both of which use energy intensive tools.

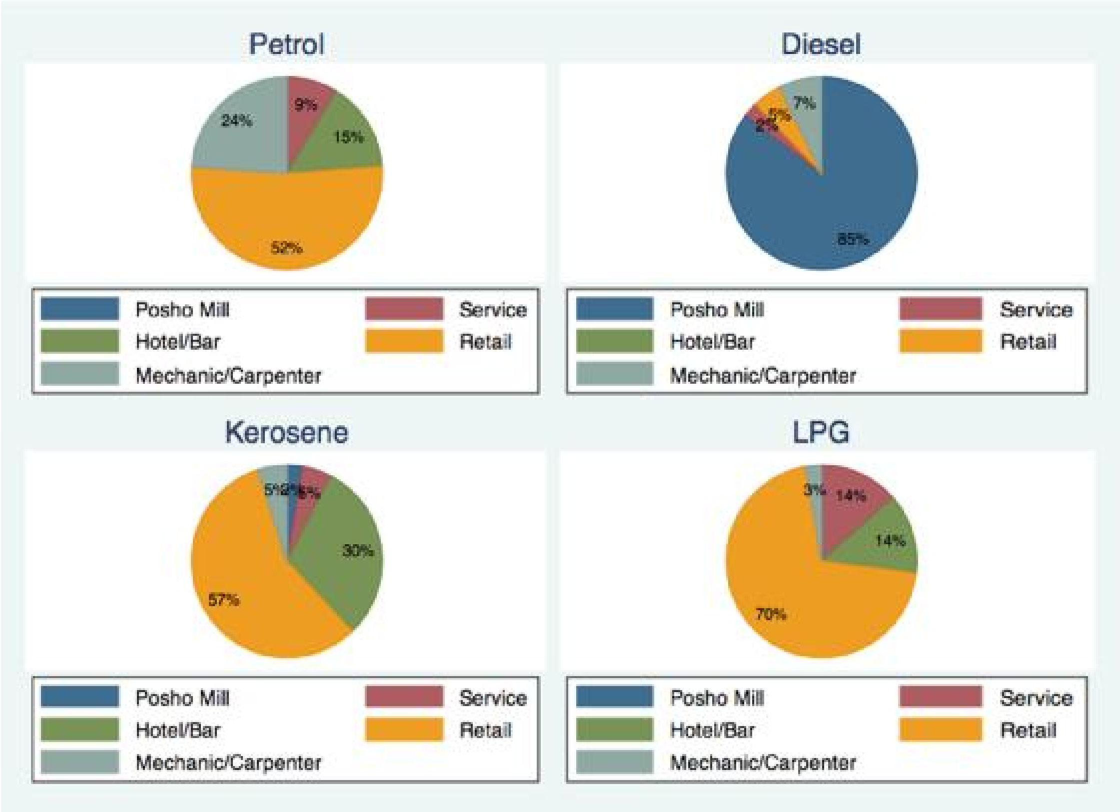

Figure 3.12: Percent of Fuel Used by Business Type

Figure 3.12 above shows what percentage of the total volume of each fuel type is consumed by each business category. This allows us to see where fuels are being consumed and the different primary uses for each fuel across business types. Petrol is used by many retail stores, but is also consumed heavily by mechanic/carpenter businesses where it is used primarily in generators to produce electricity. Posho mills use diesel almost exclusively, and consume the majority of diesel in the commercial centers. This is largely caused by the fact that the standard milling machinery runs on a diesel engine. Kerosene is used primarily in retail stores for lighting after dark, however it is also used frequently in hotels and bars for lighting as well as cooking. Most LPG is consumed in retail stores, where it has disparate uses. Overall, it appears that petrol and diesel are used much more often by energy-intensive businesses, while kerosene and LPG are used for cooking and lighting.

3.4.3 Distance Traveled for Fuel by Users

Previously, we examined the distances traveled by fuel sellers to the point of purchase. Similarly, we can compare the distance traveled by fuel users, the end consumers, to their purchase points.

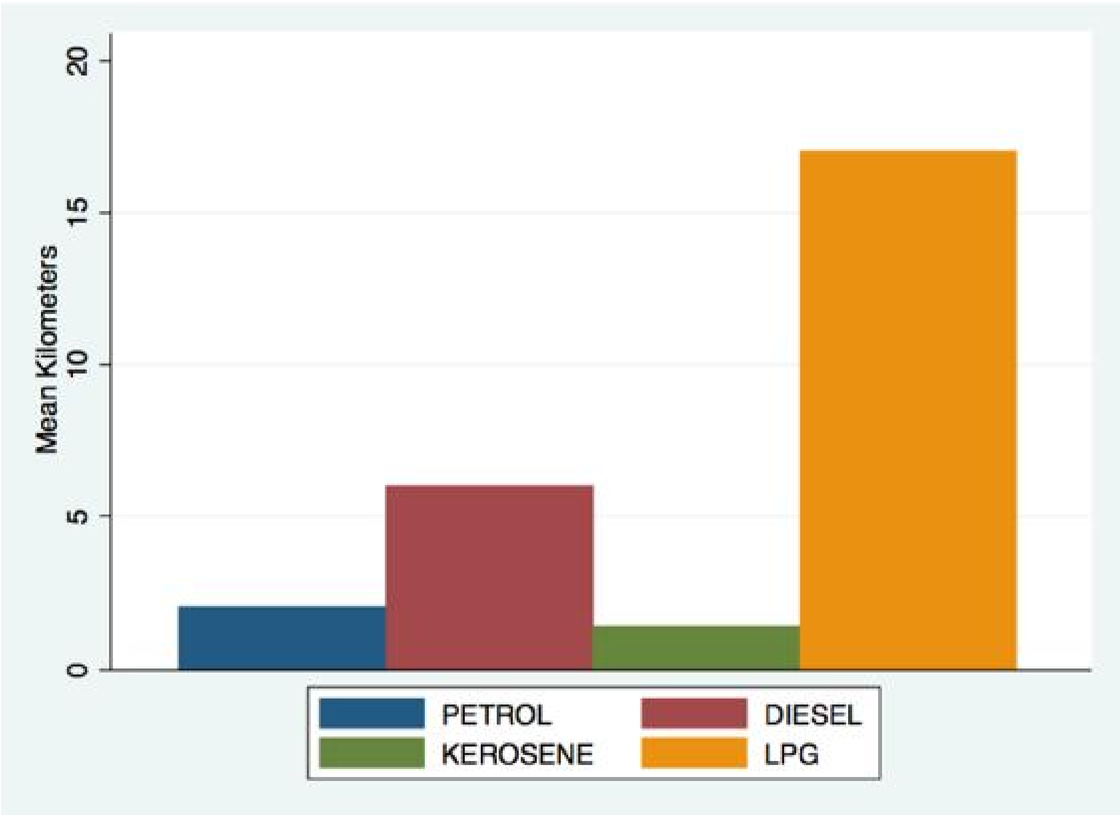

Figure 3.13: Kilometers to Fuel Source

Comparing the figure above with the distances traveled by sellers, we can see that, on average, users travel vastly shorter distances in order to obtain fuel. Consumers of liquid fuel have to travel very short distances in order to obtain petrol and kerosene and only slightly further to obtain diesel (6 km). LPG is still difficult to obtain, likely a result of the smaller number of stores selling LPG in the survey area. Overall, this indicates that fuel sellers within the blocks have made fuel reasonable easily available to consumers. However, we cannot account for the fact that more businesses might use a fuel type if it were more easily available in their center. For instance, some businesses may not use a petrol generator because petrol is not easily accessible nearby.

Another method of examining the availability of liquid fuels is the proportion of businesses indicating that they were able to purchase fuel types from within their own commercial center. This is defined as any business that did not need to travel outside of their local community (on the map in Figure 3.1 these are the black dots) to find fuel for consumption.

Table 3.4: Local Purchase by Fuel Type

Fuel Used	Percent Purchased Locally
Petrol	67%
Diesel	30%
Kerosene	82%
LPG	8%

Table 3.4 demonstrates that the percent of fuel purchased locally matches what one would expect from the average distances traveled. Petrol and kerosene are both purchased locally the most often and sourced from the shortest distance away. On the other hand, only 8 percent of LPG users were able to purchase locally, with many reporting that they traveled to Kisumu to purchase their fuel as needed.

As in the study of fuel sellers, we have examined the types and amounts of fuel used by businesses in the commercial centers. Additionally, we have further explored the end uses of each fuel type and their role in the local economy. Lastly, we saw that while fuel users do travel some distance to purchase fuel, in general they travel much lesser distances than sellers of a given fuel type.

3.5 Transporters

Finally, we turn our discussion to fuel use by transporters, a category which includes *boda-bodas* (motorcycle taxis) and *matatus* (small public buses). The data for transporters was collected in two stages. In the first stage, we collected data on *boda-bodas* from each commercial center in the sample. Drivers were interviewed in each commercial center concurrently with the business survey. Interviews were conducted with drivers waiting for a customer or any driver who arrived during the survey team's visit. Up to ten *boda-boda* drivers were interviewed in each center. In total, 296 *boda-boda* drivers were interviewed in the 56 commercial centers within the five survey blocks. All *boda-boda* drivers in the sample were male and were 29 years old on average. Compared to store owners, *boda-boda* drivers are much less educated. While 78 percent of the sample had completed primary school, only 25 percent had completed secondary school and only two percent had any college education.

In the second stage, we collected data from *matatu* drivers on routes that served any of the five survey blocks. Thirteen *matatu* routes were identified in the survey region; these cover all *matatu* routes in the region. In total, 77 *matatu* drivers driving the 13 separate routes were interviewed. These 13 routes were split among the five blocks in the following manner: three serviced Lower-Nyando, four were in Mid-Nyando, two in Lower-Yala, three in Mid-Yala, and one in Upper-Yala. Similar to *boda-boda* drivers, all the *matatu* drivers were male and were on average 35 years old. They were slightly more educated than *boda-boda* drivers with 88 percent having completed primary school, 29 percent secondary school, and five percent some college education.

3.5.1 Fuel Use by Transporters

In order to estimate the total fuel used by transporters within each block we need two pieces of information. First, we need to know the average fuel used by a *boda-boda* or *matatu* driver for their respective route or commercial center. Second, we need an estimate of the total number of transporters servicing that route or center. The first number was calculated by averaging the monthly fuel amount used by drivers within each route or commercial center. Monthly fuel amounts used were themselves calculated by multiplying self-reported daily fuel consumption by the number of days of the week worked, then normalized to a month. Daily fuel use was used because this amount is likely to be reported more accurately than estimated monthly or weekly consumption.

The total number of transporters servicing an area was generated in one of two ways. Where possible, the number was gathered from official cooperative lists of registered *boda-bodas* or *matatus* drivers. When these lists were unavailable, the total number of transporters servicing an area was calculated by averaging drivers' reported information on the total number of drivers operating each the route or at each center. Obvious outliers were dropped when calculating these averages. Using this method, the estimated total population of *matatus* servicing the survey area is 598, while the total number of *boda-bodas* servicing all 56 commercial centers is approximately 1,700. Note that the estimate of the number of *boda-bodas* is rougher than the number of *matatus* as there were fewer *boda-boda* co-operatives from which to draw a more precise count of drivers.

The figures below display the total amount of fuel used by transporters within the service area. The first, Figure 3.14, shows the estimated monthly amount of petrol used by *boda-boda* drivers across each block. Note that all *boda-boda* drivers used petrol for their motorbikes. The second, Figure 3.15, does the same for *matatu* drivers, while the third, Figure 3.16 combines them to arrive at total fuel use estimates.

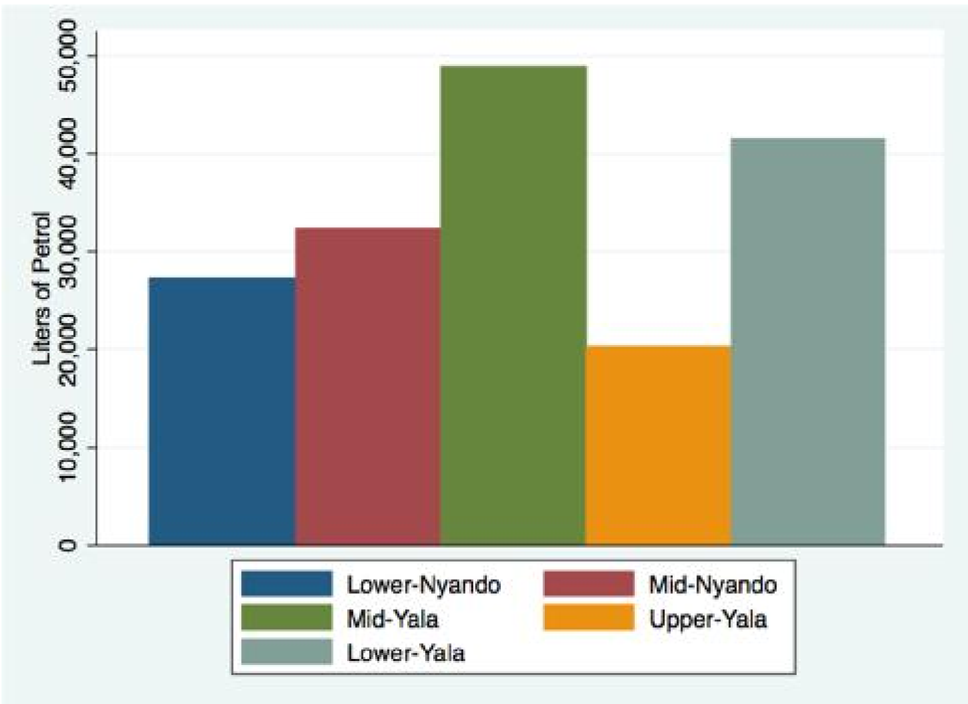

Figure 3.14: *Boda-boda* Estimated Monthly Petrol Demand by Block

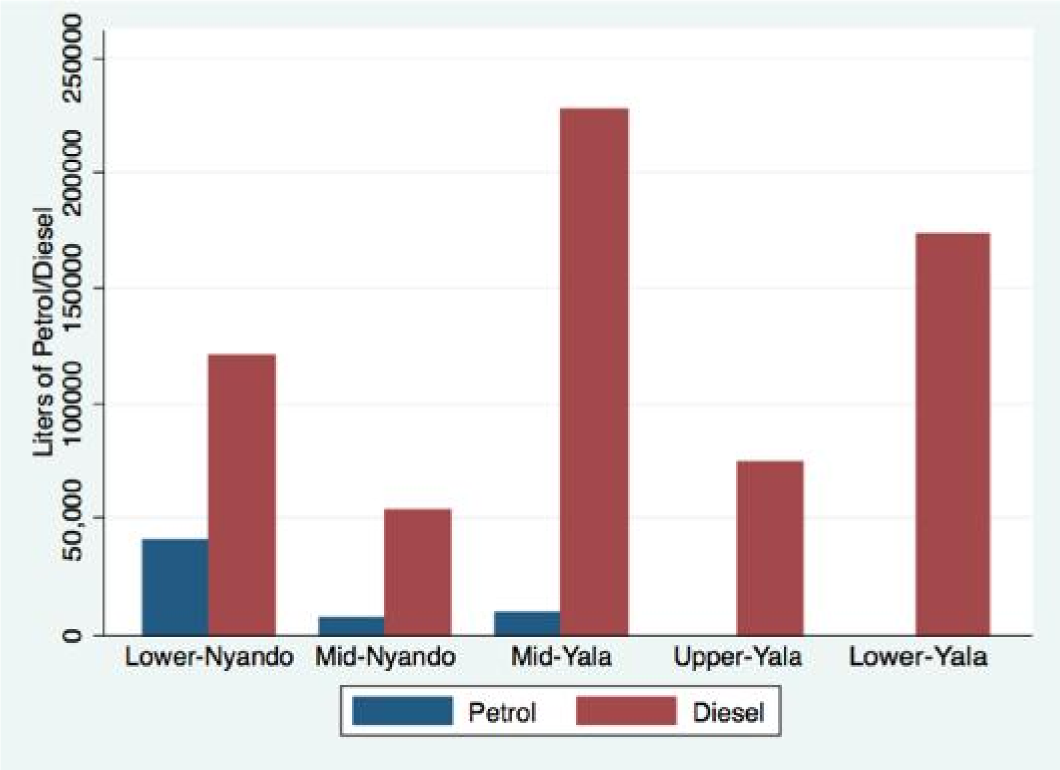

Figure 3.15: *Matatu* Monthly Demand by Block

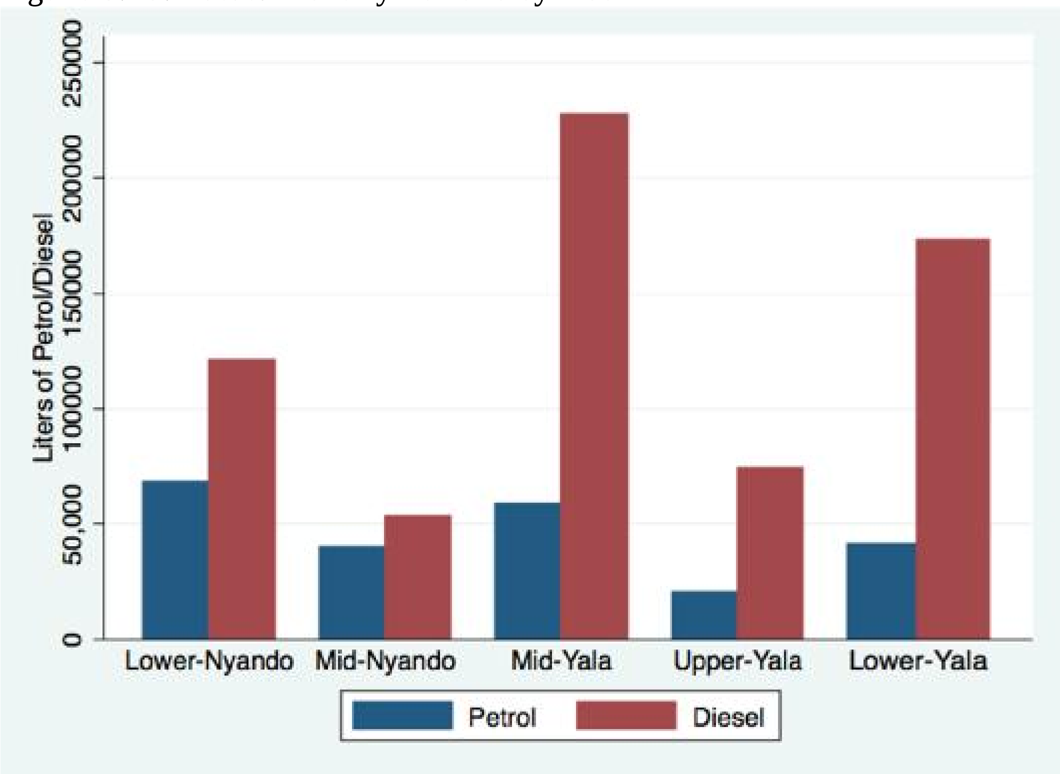

Figure 3.16: Total Monthly Transporter Fuel Demand

Examining the three figures above, the Mid-Yala block has the highest transport fuel demand of the five blocks for both *matatus* and *boda-bodas*. In total, transporters servicing the block consume approximately 227,000 liters of diesel and 59,000 liters of petrol per month, estimated as discussed above. Users in the Lower-Yala block have the next highest fuel consumption followed by those in Lower-Nyando. Users in the Mid-Nyando and Upper-Yala blocks consume similarly low amounts of fuel.

It should be noted that much (in some cases most) of the fuel consumed by transporters within the survey region was not purchased within the block. Many *matatu* drivers purchase fuel at the end points of their routes and *boda-boda* drivers travel to purchase fuel from commercial centers outside the survey area. However, all transporters indicated that they purchase fuel wherever it is cheapest. Thus, the figures above do represent *potential* demand within the survey area. It is interesting that the high levels of fuel petrol and diesel demand in the Mid-Yala block corresponds to high levels sold by fuel sellers, as shown in Figure 3.4. This may indicate that many transporters purchase fuel within the block. Conversely, medium levels of demand in Lower-Nyando do not correspond with sales at all, indicating that transporters from this block must purchase their fuel elsewhere.

3.5.2 Distance Traveled for Fuel by Transporters

We can begin to explore where transporters are buying their fuel by examining the distances that they travel to their main fuel source. Figure 3.17

below reports the average kilometers traveled by *boda-boda* drivers to their main fuel source from their primary commercial center. *Matatus* are not analyzed in this section because all *matatu* drivers purchased fuel at some point along their route and therefore did not need to travel any extra distance to purchase fuel.

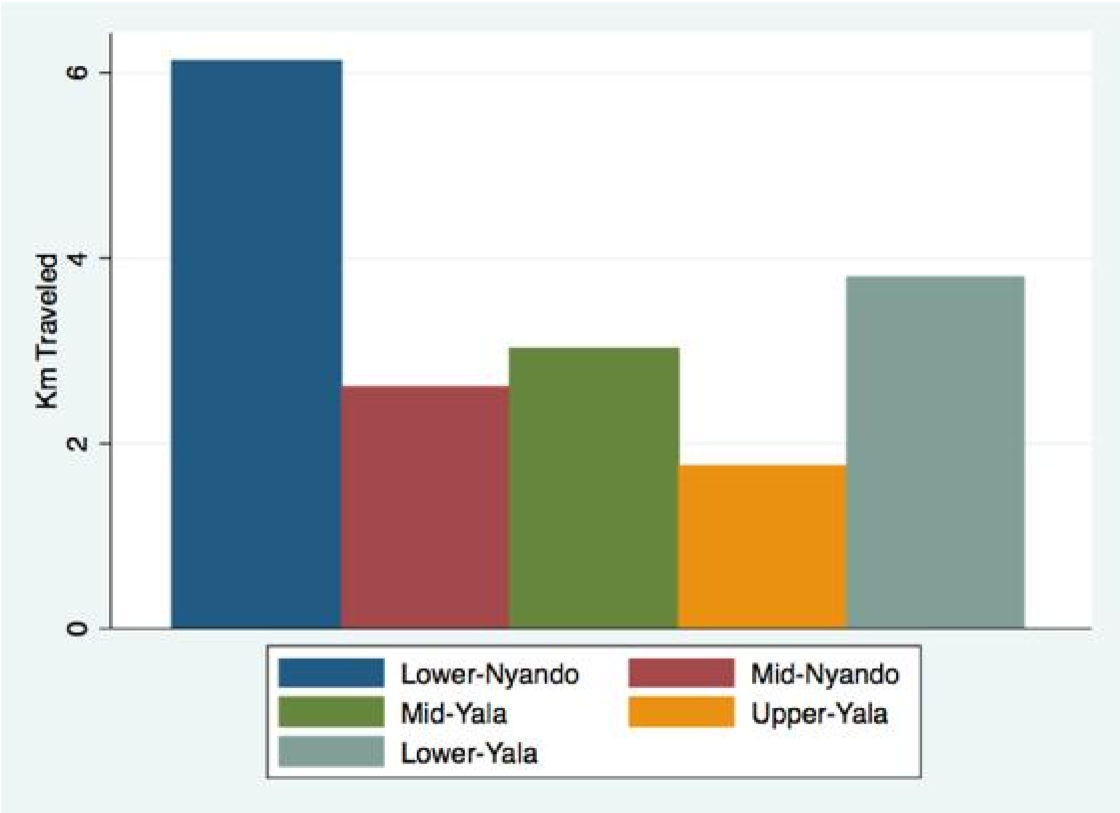

Figure 3.17: Distance Traveled to Fuel Source by Boda-boda Drivers

Transporters in Lower-Nyando travel the farthest average distance to their fuel source, going about 6 km on average. The rest of the sample travels considerably shorter distances, ranging from about 2 km in Upper-Yala to under 4 km in Lower-Yala. These distances also support our previous observation that transporters in a block may be buying fuel outside the survey area due to the incongruity of fuel demand and fuel supply. Additionally, the Lower-Nyando block lacks access to a petrol station (although there are individual petrol sellers), which could lead transporters to travel greater distances to access fuel and hence experience higher transaction costs.

Using additional data from the survey, we can estimate the magnitudes of these extra travel costs. First, we roughly estimate the average liters used per kilometer for *boda-boda* drivers in the sample. To do this, we take the daily number of liters used and divide it by daily distance traveled. Second, using the average reported price per liter of petrol in the sample (128 KES) we can estimate fuel cost per kilometer traveled. We find that, on average, it cost drivers 11.2 KES per kilometer they drive (this translates to an average km/L of 11.5). Lastly, we can estimate that *boda-boda* drivers in Lower-Nyando bear at least an additional 22 KES cost to refuel than drivers in other blocks. However, these estimates should be regarded as very rough estimates due to the presence of measurement errors in the distance-traveled variable.

Finally, we can calculate *boda-boda* driver's average revenue per kilometer driven with a customer. Using data collected on the cost of a one-person ride to the next commercial center, we estimate the average per-kilometer cost of a *boda-boda* ride at 15.8 KES. Subtracting off the estimated cost-per kilometer we arrive at a per kilometer net revenue of 4.6 KES (approximately .05 USD[14]). This indicates *boda-boda* drivers must drive two kilometers with a customer in order to compensate for the cost of any un-paid kilometer.

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[14] Exchange rate as of May 1, 2012

In sum, the poor distribution of petroleum in rural areas can be a significant burden to *boda-boda* transporters. In areas without a close-by source of petrol, *boda-boda* drivers face difficulties in covering their operating costs. Also, many drivers rent their motorcycles and so also face a fixed daily rental cost. Due to these low revenue streams and high costs, *boda-boda* drivers are particularly vulnerable to any fuel price shock or disruption in fuel supply. As *boda-boda* drivers are numerous (an estimated 1,700 in the survey area) and serve an important public transit role to the local community, their vulnerability could have important consequences to the overall economic health of the rural economy. While drivers may be able to compensate in the long-term by raising their prices charged to customers, sticky prices plus the competition offered by bicycles, *matatus*, or walking mean that this is difficult as a short-term solution.

In this section we have shown that local transporters are numerous and represent an important source of actual and potential fuel demand in rural areas. Additionally, lack of easy access to petrol for *boda-boda* drivers in certain areas entails a significant cost to their income and makes them vulnerable to fuel price shocks.

3.6 Electricity Use

While electricity is not the focus of this study, it is a substitute for the liquid and solid fuels in the survey. Consequently, it is useful to examine the availability and price of electricity within the survey area. Electricity was nominally available in 50 of our 56 commercial centers, however, three centers were connected to the grid but did not actually have electricity. Grid extension to each commercial center was funded by using public funds, but required an up-front payment of 35,500 KES (410 USD) for each connection to the grid. After the initial connection, users are responsible for paying their monthly bill. Most private connections occur when a developer constructs new commercial buildings and pays for a grid connection as part of the construction cost. The tenant typically pays monthly costs. Electricity access within centers was almost entirely absent from individual households.

Within the commercial centers that had active access, 41 percent of all businesses used electricity as their primary source of energy, which represents nearly all businesses that had a connection. The median monthly bill was 800 KES (9.33 USD) with some large outliers resulting from energy intensive businesses such as mechanic shops or technology services.

The high percentage of businesses that use electricity when it is available demonstrates the desirability and relative cost-effectiveness of electricity as an energy source. However, of all electricity users in the sample, only three businesses (one percent) paid their own connection cost. This indicates that despite the attractiveness of electricity as an energy source, the initial cost of 35,000 KES is simply too high for the majority of businesses – and certainly, households – to pay. Until the Kenyan Power Company lowers the connection cost, or until it offers creative payment mechanisms, other energy sources will remain necessary for a significant proportion of businesses and nearly all households.

This chapter has reviewed the information collected from the surveys of energy sellers and users in the survey areas of Western Kenya. From these data, we were able to construct a snapshot of the rural energy market. Details were provided on the average price of each fuel and the quantity traded in the survey area. Additionally, the data provide a better understanding of the energy distribution network. Information on the overall availability of fuel, such as average distances travelled to energy depots and supply disruptions, provides a clear picture of supply chain limitations. In the following chapter, we continue to investigate the impacts of these supply chain limitations on rural households.

CHAPTER 4

QUNATIFYING MARKET INEFFICIENCIES

The previous chapter summarized the information collected from commercial centers in Western Kenya. In this chapter, we continue to use this detailed data set to quantitatively investigate the impacts of supply chain bottlenecks on consumers in the survey areas. We divide this analysis into two sections. First, we detail how the market imperfections in the supplies of fuel leave the poorest consumers in the most disadvantaged position. In particular, these cash-constrained households are consistently forced to pay exorbitantly high per unit prices for kerosene. Second, we use regression analysis to identify some of the specific bottlenecks in the supply chain that lead to these major market failures. Among other things, we find that distance from fuel sources, a shortage of petrol stations, and a lack of paved roads all have significant impacts in raising average fuel prices for rural consumers. We conclude with estimates of the impacts of these sources of market inefficiency in the supply chain on fuel prices.

4.1 High Costs to Consumers

As was previously discussed in Chapter 3, each type of liquid fuel serves unique purposes in different sectors of the economy. For example, petrol and diesel are consumed in relatively large quantities by transporters and energy-intensive businesses. Households and businesses, on the other hand, more often consume kerosene and LPG in small absolute quantities. Interestingly, as reported in Figure 3.6, kerosene and LPG are the two most expensive fuels on a per liter basis. It seems strange that the most cash-constrained consumers would choose to purchase the most expensive fuel to meet their domestic needs. However, in Figure 4.1, we can see that this story changes when we only include prices from stores selling *actual* liters of fuel. The difference can be explained by the fact that while petrol and diesel are sold almost exclusively in liters, kerosene sellers frequently offer their customers smaller quantities but at a higher *per unit* price. This practice has the effect of making the average per unit price of kerosene appear higher than that of petrol or diesel, when it is in fact the cheapest of the three. Figure 4.1 below displays the mean price of a liter (or bundle) of each fuel.

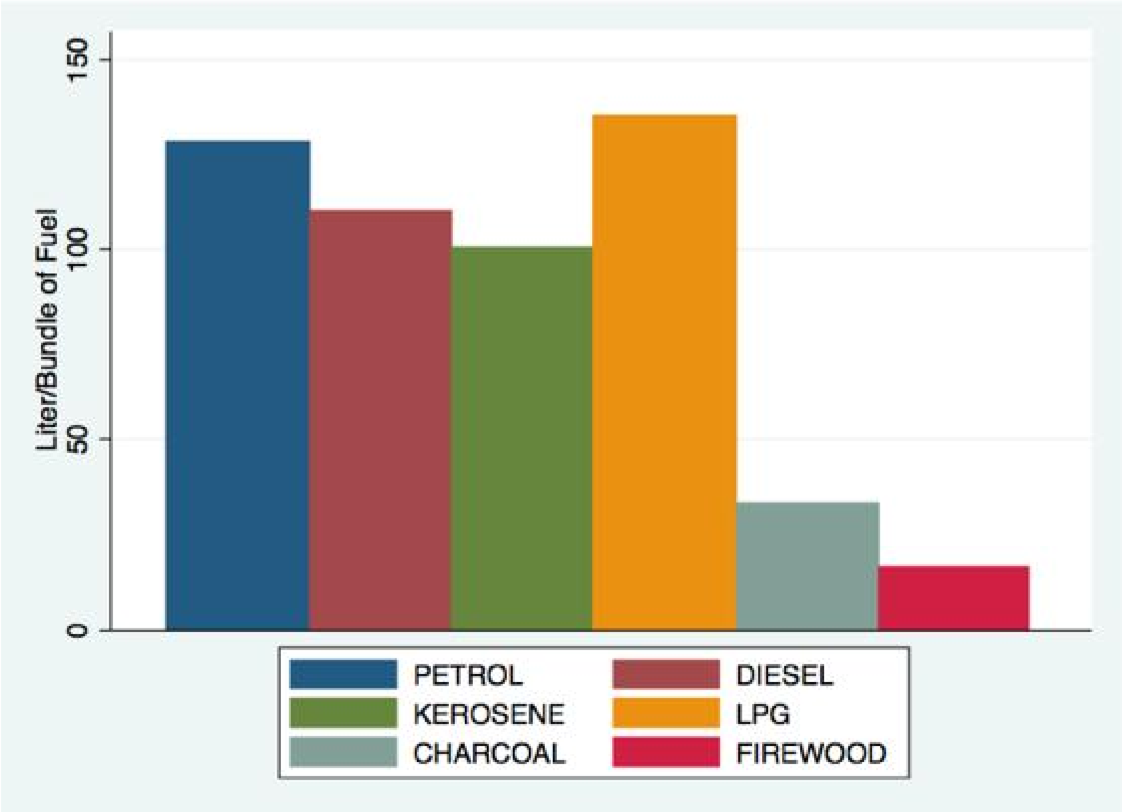

Figure 4.1: Mean Price of Fuel

The price of kerosene in the figure above has dropped from the previously reported 141 KES to a much more reasonable 100 KES. This large drop in average price indicates that small quantities of kerosene are being sold at a very high *per unit* price when compared to a liter. The most common small units of kerosene sold in the survey area are called "*kibabas*". *Kibabas* are small metal dips, often made out of the bottom of tin cans, which are used to doll out kerosene from a larger container. The kerosene is then put into a plastic bag or other receptacle and sold to the customer. The survey recorded three different sizes of *kibabas*, which are named after the price they commanded. A 20 KES *kibaba* contained 135ml of kerosene on average, a 10 KES *kibaba* 55ml, and a 5 KES *kibaba* 20ml.

It is worth pointing out explicitly that due to the fact that *kibabas* are *defined by their price* rather than quantity, prices for kerosene sold by the *kibaba* are fixed throughout the survey area. The volume of each *kibaba* size was calculated by a simple average of ten *kibabas* collected from businesses within the survey area. These averages were then used to calculate the *per liter* price of kerosene based on which *kibaba* size a consumer purchased. Figure 4.2 below presents the price per liter of each of the three *kibaba* sizes alongside the one liter price.

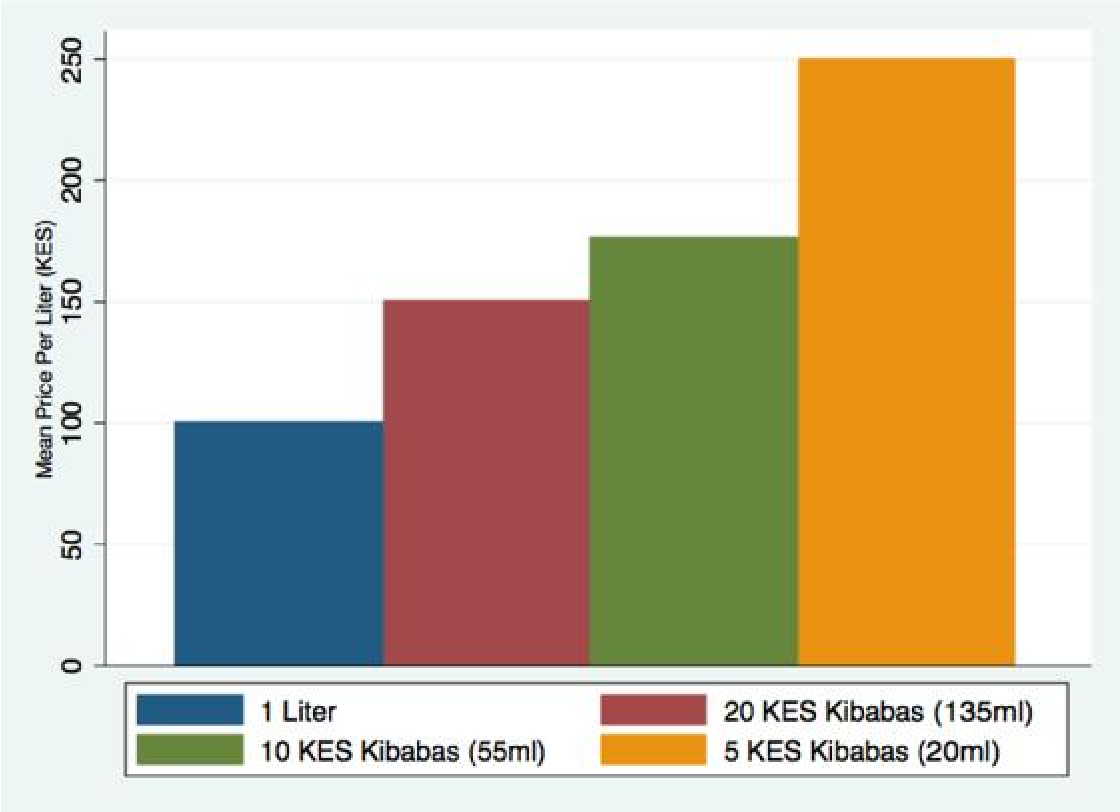

Figure 4.2: Price per Liter of Kerosene

Immediately apparent from Figure 4.2 is the fact that the five-schilling *kibaba* costs a staggering 250 KES on a per liter basis, a 150 percent increase from the per unit liter price. Prices fall quickly as volume rises, with a ten-schilling *kibaba* costing 176 KES per liter and a twenty-schilling *kibaba* priced at 150 KES per liter. These compare with an average price of 100 KES for a full liter of kerosene, meaning that even the largest *kibaba* is priced an exorbitant 50 percent increase above the per unit liter price.

What emerges from decomposing the price of kerosene is that poor consumers are purchasing fuel at a very high mark-up relative to consumers that can afford larger quantities. These consumers wisely use kerosene, as it is the cheapest of the liquid fuels on a liter basis. However, for various reasons, particularly cash constraints, consumers often purchase small amounts of kerosene at a very high cost rather than larger amounts at a relatively cheap cost. This implies that most rural households and businesses are spending at least 50 percent more for their daily fuel than they would if they could purchase it in larger quantities. As kerosene is by far the most common type of fuel sold within the survey area, this extra cost is economically significant.

There are at least two reasons why households and businesses may be unable to purchase larger quantities of kerosene. Cash constraints are the primary reason, as many consumers do not have the savings to purchase a full liter of kerosene up front. However, a second overarching factor is that many consumers lack access to more efficient energy distributors. First, this is due to the steep cost of connecting to the electrical grid which prevents most rural consumers from using relatively cheap electricity. Second, the shortage of efficient liquid fuel distributors, such as gas stations, cuts rural consumers off from the cheaper liquid fuels they provide. In this market environment, retail stores selling kerosene at a large mark-up are often the only option available. The next section of our analysis attempts to further analyze the cost to consumers resulting from poor distribution networks. In particular, we estimate the effects of specific market variables on fuel prices.

4.2 Regression Analysis: Cost of Distribution Constraints

In this section we will use linear regression models to estimate the impacts of the poor distribution system on the fuel prices faced by rural consumers. Our dependent variable of interest (Y) is the *per unit* price of fuel as it was reported by energy sellers in the commercial center survey. As before, we fix the standard unit as a liter of fuel.

Our choice of independent variables reflects the distribution bottlenecks that were identified in the policy review and in the survey summary statistics reviewed above. Using the commercial center data, we are able to investigate the impacts of the poor physical infrastructure, low degree of market competition, and underservice by oil marketing companies (OMCs) on the fuel prices paid by rural consumers. The follow equation presents a general reduced form model using these three main factors as the determinants of per unit price.

$$Price_i = \beta_0 + \beta_1(Access\ to\ OMCs_i) + \beta_2(Infrastructure_i) + \beta_3(Competition_i) + \varepsilon_i$$

To estimate this model, we have identified four principal independent variables within the data set that serve as a proxy for each of these factors. The first variable of interest is a consumer's access to large oil marketing companies (OMC). For the first of two proxies for this variable, we use survey data on the distance each energy seller traveled to their fuel source. Most independent energy sellers purchase their fuel from larger OMCs for resale in their local communities. In areas with poor market penetration by these firms, independent energy sellers will have to travel greater distances in order to secure their fuel supplies. The further a seller must travel, the higher that business' transport costs are likely to be. Many of these businesses will then pass on some of those extra costs to their customers in the form of higher prices. Thus, a region that is underserved by efficient oil marketing companies is likely to have high fuel prices as individual sellers travel large distances to provide fuel to the customers in the area.

However, we expect that this effect will be non-linear, and thus hypothesize that the effect of distance on prices follows a quadratic form with diminishing marginal effects. The reasoning behind the quadratic assumption is that much of the cost of transport occurs at shorter distances, when a business is forced to move from a cheap type of transport to a more expensive one. For example, at very short distances, a business may be able to rent a handcart or bicycle to transport fuel. After a few kilometers it is necessary to use a much more expensive *boda-boda* or *matatu*. However, once the jump to a more expensive form transport has been paid for, further cost increases according to distance traveled will rise much more slowly. For these reasons, our hypothesis is that the coefficient on distance traveled will be positive and the coefficient on the square of distance will be negative. This implies a positive effect of distance to fuel source on price but with decreasing marginal effects.

Our second proxy for OMC access is simply a dummy variable for whether or not an energy seller is classified as a gas station (yes = 1; no = 0). Gas stations are defined as any energy seller that uses a metered pump to dispense liquid fuel. Gas stations are able to operate much more efficiently than independent sellers that do not have a gas pump. Gas pumps allow fuel to be stored more effectively and allow sellers to accurately charge for irregular quantities of fuel. Gas stations are also more easily able to sell to vehicles, increasing their volume sold and allowing sellers to achieve economies of scale. Additionally, all but one of the gas stations captured in the commercial center survey were actually owned and operated by larger OMCs. This implies that the gas stations are part of a larger efficient distribution network, further reducing transaction costs. The combined effect of these efficiency gains makes it likely that gas stations are able to sell cheaper fuel than other energy sellers. Thus, our hypothesis is that the coefficient on the gas station dummy variable will be significantly negative.

The second variable of interest is the quality of physical infrastructure serving a commercial center. To estimate the impact of infrastructure's effects, we use a proxy dummy variable for whether or not the commercial center was serviced by a tarmac road (yes = 1; no = 0). Paved roads are important for fuel prices as they lower transport costs for energy sellers. In areas without paved roads, seasonal rains can make delivery of fuel by truck, or even *matatu*, unviable. This limits transport options to *boda-bodas* or manual labor, both of which are more expensive and constrain the amount of fuel that can be transported at one time. These increased transport costs will likely be passed onto consumers. For this reason, our hypothesis is that the coefficient on the tarmac variable will be negative.

The last important variable in our general model is the level of competition in the energy market. To account for competition, we use data on the number of energy sellers servicing a given commercial center. This number presumably reflects the energy market competition in each commercial center. If there is only one provider of fuel within a commercial center, then as a local monopoly that business may charge higher prices. Conversely, commercial centers with multiple energy sellers will have greater competition and lower fuel prices. Therefore, our hypothesis is that variable representing the number of stores in each commercial center, a proxy for level of competition in the local fuel market, will have a negative coefficient.

In addition to the main variables of interest we also include a vector of variables (X), which contain controls for the type of fuel sold and for the unit size (such as a *kibaba*) being sold. These controls will account for the inherent price differences between fuel types and differences due to volume.

With these variables specified, our general model becomes the following reduced form equation:

$$Price_i = \beta_0 + \beta_1(Distance_i) + \beta_2(Distance\ Squared_i) + \beta_3(Station_i) + \beta_4(Tarmac_i) + \beta_5(Stores_i) + \beta_6 X_i + \varepsilon_i$$

To estimate this model, we use the data collected from energy sellers, which were described and summarized in Chapter 3. The observations are organized by store and fuel type, which means that a single energy seller may account for multiple entries. For instance, a business that sells both petrol and diesel will account for two observations in the data set.

Additionally, the analysis will be limited to the liquid fuels: kerosene, petrol, diesel, and LPG. We exclude charcoal and firewood from the data set because the fuel distribution networks we are interested in do not deal with either of these fuels. Indeed, charcoal and firewood are most commonly produced and distributed locally, bypassing any need for efficient regional distribution channels. This data restriction reduces the number of energy sellers in our sample from 137 to 126. Of these 126 businesses, eight had missing data and were excluded from the analysis. The remaining sample of 118 individual businesses accounts for the total number of 137 fuel-price observations that we use to estimate our model.

There are several potential econometric problems with this estimation equation that should be addressed. First, our four main variables of interest, distance traveled, number of stores, tarmac roads, and gas stations, may be highly correlated with one another. For example, commercial centers further from fuel distribution points are likely to contain fewer energy sellers, and are less likely to have a gas station or tarmac road. If these variables are too closely correlated, then we will have difficultly isolating the effect of a single variable on per unit price. Nevertheless, it is also important to include all variables in the regression so that our estimates are not biased by an omitted variable. We can examine the degree of correlation between our explanatory variables in the following correlation matrix.

Table 4.1: Correlation Matrix

	Distance	Tarmac	Station	Number
Distance	1	-	-	-
Tarmac	0.0943	1	-	-
Station	0.3194	0.3046	1	-
Number	0.0724	0.1144	0.0946	1

The highest correlation between variables is a relatively low 0.32, between "Distance" and "Station". In light of the reported correlation matrix in Table 4.1 and extensive preliminary regressions – results not reported here – we are confident that multicollinearity is not a problem.

A second potential problem is that some of these variables may be endogenous with price. For instance, tarmac roads may be strategically built by the government in communities with more economic activity and better pre-existing distribution systems. These factors may also be associated with lower fuel prices. As a consequence, fuel prices could be endogenously linked with the construction of a tarmac road. This reverse causality scenario would bias our estimates. However, in reality this does not appear to be the case. Tarmac roads in Kenya are mostly constructed to link larger metropolitan areas. The decision of where to place these roads is made at the national level, and the small commercial centers that make up our survey would not factor into this decision-making process. The commercial centers that happen to randomly lie on the corridor between these locations may be accessed by a tarmac road while other centers do not. Therefore, we can reasonably assume that tarmac roads are exogenous to fuel prices.

The number of stores operating in a commercial center may also be endogenous, as energy sellers may decide to open for business in response to high fuel prices. We can test this hypothesis by examining whether the number of stores in a commercial center is correlated with other variables that we think influence fuel prices. If prices were causing stores to open and close, conditions that impact prices (such as distance to fuel sources) would also impact the number of stores in a center.

From Table 4.1 above, we see that the correlation between the distance traveled to fuel source and the number of stores in the commercial center is very low at 0.07. This indicates that commercial centers that are physically isolated from fuel distribution points do not have an appreciably different number of stores than more well-connected centers. Conversely, tarmac roads may attract stores to commercial centers. The average number of stores in centers with a tarmac road is 3.6, while centers without a tarmac road have a mean of 3.2 stores in the survey region. This is consistent with our hypothesis that improved infrastructure would improve access to fuels. Additionally, as we discussed previously, tarmac roads are constructed randomly through commercial centers, which reduces the possibility that stores are attracted commercial centers with pre-existing low prices.

In addition, we also assume that distance traveled to fuel source and gas stations are exogenous. Fuel prices in a commercial center are unlikely to influence travel distances between the center and distribution points. Similarly, prices in a commercial center are unlikely to influence whether or not a business operates a fuel pump.

A final econometric problem is that there may be spatial correlation between the error terms of the model. In the data set, there are multiple energy seller observations (up to six individual businesses) drawn from each commercial center. Given the common market environment shared within each commercial center, it is possible that unobserved variables associated with an individual center will impact prices for each local business in the same way. This common "shock" will cause error correlation between businesses located within the same commercial center. Spatial correlation of this type would violate our "i.i.d." (independent and identically distributed) error-term assumption, and cause our usual standard error calculations to be inconsistent. A simple Breusch-Pagan test returned a Chi-squared test statistic of 9.94, which suggests that our error terms may indeed be correlated. However, we can maintain our assumption that errorterms are independent across our commercial center groups.

To adjust for this problem, we use “cluster-robust” standard errors grouped at the commercial center level. This correction will account for correlation within commercial centers by calculating a cluster-robust variance-covariance matrix[15]. The cluster-robust matrix is calculated by first summing the squared errors from the regression *within* each of the 56 commercial centers groups, and then adding these squares *across* all groups. This correction allows for accurate hypothesis testing in the face of either heteroskedasticity or intra-group correlation in the error terms.

Now that the model and key variables in our equation have been described, we present the results obtained from OLS regression in Table 4.2 below. The dependent variable in this regression is the per unit price of fuel.

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[15] The cluster-robust variance-covariance matrix is given by the following formula taken from Cameron and Trivedi (2005):

$$\left(\sum_{c=1}^{C} X_c' X_c\right)^{-1} \sum_{c=1}^{C} X_c' \widehat{u_c} \widehat{u_c}' X_c \left(\sum_{c=1}^{C} X_c' X_c\right)^{-1}$$

Where X_c is a matrix of the within cluster observations and $\widehat{u_c}$ are the estimated errors from the regress equation. This formula places no restrictions on heteroskedasticity and correlation within the cluster and is consistent as the number of clusters approaches infinity.

Table 4.2: Linear Regression Results

VARIABLES	Per Unit Price
Distance to Fuel Source	0.312**
	(0.127)
Distance Squared	-0.00180**
	(0.000774)
Gas Station	-8.962***
	(2.303)
Tarmac	-3.539
	(2.446)
Number of Stores	-1.684
	(1.041)
Petrol	-2.754
	(3.352)
Diesel	-19.04***
	(3.853)
Kerosene	-30.05***
	(4.183)
Constant	134.7***
	(5.630)
Observations	137
R-squared	0.911
Probability > F	0.000

Cluster standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4.2 above reports the beta coefficients and cluster standard errors for our four main variables of interest and three fuel types (LPG is the base case). Both the 0.91 R-squared and the F-statistic of 1281.1 (p-value<.01) from a joint significance test indicate that overall model has strong explanatory power. However, this level of fit is largely a consequence of the dummy variables for kerosene, petrol, and diesel, as prices tend to move incrementally around a mean fuel price.

Our first variable of interest, distance to fuel source, has a positive coefficient of 0.312 on its linear component and a negative coefficient of -0.0018 on the quadratic. Both of these coefficients are significant at the five percent level. This implies that at short distances the marginal effect of one more kilometer increases price by approximately 0.3 KES. However, the marginal impact decreases at larger distances. At 20 kilometers (the mean distance in our sample), the marginal impact of increasing the distance to the fuel source by one kilometer is only 0.24 KES. This effect is economically as well as statistically significant, as it implies a fuel price increase of 6.38 KES at 20 kilometers. These results confirm our hypothesis that distance to fuel source has a positive impact on prices with decreasing marginal effects as distance increases.

The second main explanatory variable, the seller being a gas station, has a coefficient of -8.96 that is significant at the one percent level. This coefficient indicates that businesses that use a fuel pump sell fuel nearly nine KES per liter cheaper on average. Nine schillings represents a nine percent lower price from the mean liter price of kerosene (100 KES) in the sample. This result clearly indicates cost savings that efficient fuel distributors can pass onto consumers. Consumers in rural areas without access to the larger OMCs that use a fuel pump technology immediately pay nearly 10 percent more than consumers with access. This result confirms our hypothesis that gas stations will have a highly negatively impact on fuel prices.

The coefficient on the tarmac variable is -3.54, but is not statistically significant, with a p-value of 0.15. The coefficient indicates that a tarmac road leads to a lower average fuel price by 3.5 KES, which is in line with our hypothesis. However, this estimate is uncertain and we cannot rule out the null hypothesis that the effect of tarmac roads on fuel prices is zero. One possibility for the non-result is that the correlation between gas stations and tarmac roads is just high enough that our OLS estimator has difficulty differentiating their separate effects. To the extent that a tarmac road encourages the location of gas stations in certain commercial centers, these two effects may be linked.

Similarly, the coefficient on the number of stores selling fuel in a commercial center is -1.68, but is not statistically significant, with a p-value of 0.11. The coefficient estimate implies that the presence of each additional energy seller in a commercial center lowers fuel prices by about 1.7 KES. Again, the direction of the coefficient confirms our intuition, but we cannot rule out the null hypothesis that the impact of the number of stores on fuel prices is zero.

4.3 Robustness Checks

In this section we will break down the results present presented above in Table 4.2 to test their strength. The first robustness check examines the assumption that the liquid fuels are each affected equally by distribution network constraints. The previous results used data from petrol, diesel, kerosene, and LPG pooled together. It is then reasonable to question whether the results discussed above pertain to all fuels together or to each fuel type individually (e.g., a subset of the sample). To answer this question, we present the same OLS regression results for kerosene, petrol, and diesel separately in Table 4.3. LPG is omitted because there are only six LPG sellers who also reported the distance to their fuel source and regression omits most variables due to colinearity. As before, the dependent variable in each regression is per unit price of fuel.

Table 4.3: Linear Regression Results by Fuel Type

VARIABLES	(1) Kerosene	(2) Petrol	(3) Diesel
Distance to Fuel Source	0.349**	0.111	0.299
	(0.164)	(0.253)	(0.358)
Distance Squared	-0.00208**	-0.00285	-0.00433
	(0.000926)	(0.00467)	(0.00584)
Gas Station	-15.82***	-4.072*	-1.702
	(4.227)	(2.021)	(2.446)
Tarmac	-1.815	-11.80***	-2.084
	(2.995)	(2.525)	(5.202)
Number of Stores	-1.878	-1.018	-0.258
	(1.533)	(0.795)	(0.710)
Constant	104.7***	132.0***	109.2***
	(5.053)	(3.454)	(4.597)
Observations	95	17	18
Probability> F	0.000	0.001	0.803

Cluster standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4.3 above shows that the data from kerosene sellers is the primary driver behind the pooled results. Kerosene observations make up 69 percent of the total sample size. Additionally, the estimated coefficients and significance levels from the kerosene regression are quite similar to the pooled results. However, both the petrol and diesel regression coefficients agree in sign with those in the kerosene equation and generally have comparable magnitudes to the estimates from the pooled results as well. Due to the smaller sample size for these two fuels, the results are necessarily noisier but they seem to tell the same story. Given that the overall results from the three regressions largely agree with one another, it is safe to assume that the pooled results hold for all three of the liquid fuels.

As a second robustness check, we estimate alternative model specifications to examine whether our results are dependent on a particular specification. For our first alternative, we change the functional form relationship between distance from fuel source and price to a log-log relationship. As an added benefit, the log-log relationship also allows us to directly estimate the elasticity of price on distance. Our second alternative assumes a simple linear relationship between price and distance. Our alternative specifications both deal with the relationship between distance to fuel sources and price. We are limited to these options due to the fact that our other explanatory variables are dummy variables. We present the results of both models together in Table 4.4 below. The dependent variable in alternative one is per unit *log*-price of fuel while the dependent variable in alternative two is per unit price of fuel.

Alternative 1:

$$\ln(Price_i) = \beta_0 + \beta_1(\ln(Distance_i)) + \beta_2(Station_i) + \beta_3(Tarmac_i) + \beta_4(Stores_i) + \beta_5 X_i + \varepsilon_i$$

Alternative 2:

$$Price_i = \beta_0 + \beta_1(Distance_i) + \beta_2(Station_i) + \beta_3(Tarmac_i) + \beta_4(Stores_i) + \beta_5 X_i + \varepsilon_i$$

Table 4.4: Alternative Model Regressions

VARIABLES	Alternative 1 Log-Price	Alternative 2 Price
Log-Distance to Fuel Source	0.0181**	
	(0.00854)	
Distance to Fuel Source		0.137*
		(0.0790)
Station	-0.0700***	-8.207***
	(0.0147)	(1.989)
Tarmac	-0.0316	-3.610
	(0.0217)	(2.448)
Number of Stores	-0.0122	
	(0.00896)	
Petrol	-0.0402	-2.747
	(0.0244)	(3.737)
Diesel	-0.183***	-20.33***
	(0.0238)	(3.832)
Kerosene	-0.293***	-30.63***
	(0.0270)	(4.390)
Constant	4.921***	131.9***
	(0.0448)	(4.736)
Observations	135	137
R-squared	0.874	0.906
Probability > F	0.000	0.000

Cluster standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The proposed alternative models produce results similar to the base regression equation. Both the signs and significance levels on the coefficients largely remain the same in each regression. The only exception is that distance to fuel source is only significant at the ten percent level in the linear model. Furthermore, neither alternative model appears to present a better fit than our original base case regression, with all three models explaining the data similarly (although a direct comparison of the log-log model with the linear models is impossible). The consistency in estimates between these models seems to support the validity of our original results.

In sum, the regression analysis above identifies some of the many failures in the fuel supply chain and attempts to quantify their impacts on fuel prices paid by rural consumers. These variables can offer a strong explanation for the curious fact that the poorest rural consumers often pay the highest per unit fuel prices. The two most important factors that increase fuel costs in rural communities are the lack of access to gas stations and long distances traveled by energy sellers to their fuel sources. Without the benefit of transportation, poor consumers are less likely to be able to access gas stations and will be confined to purchasing fuel from local community sources. This excludes these consumers from significant savings, as gas stations are by far the cheapest suppliers of liquid fuel, averaging nearly 9 KES less per liter than their competitors. There are a number of factors that likely led to these lower prices, including higher sales volume allowing economies of scale, access to efficient long distance transport networks, and more efficient operating technologies (e.g., electric gas pumps) which reduce transaction costs.

The distance traveled to fuel sources is the other most important factor in determining fuel prices. Independent energy sellers that service rural communities need to transport their fuel from a distributor, often located at a significant distance, to their store. These extra transport costs are passed onto consumers, with a 20 kilometer distance being associated, on average, with a 6 KES-plus increase in per liter price. These large distances traveled by energy sellers are also related to the low number of gas stations in rural areas. When sellers are located too far from the larger supply depots present in larger cities, they will often purchase fuel from closer gas stations for resale in their local communities. However, if these gas stations are also far from the commercial center, energy sellers will continue to transport fuel long distances. Therefore, being isolated from gas stations not only restricts consumers' access to the cheap fuel they provide, it increases the costs of fuel provided by other local independent sellers, and in turn to the consumers purchasing fuels from these sellers.

The two less important distribution problems are the lack of tarmac roads and relatively uncompetitive fuel markets. The presence of a paved road servicing a commercial center was associated with a 3.5 Kenyan Schilling (KES) per liter drop in average fuel prices. While this result is more ambiguous than those related above, it nonetheless suggests that poor road infrastructure plays a role in increasing rural fuel prices.

The number of energy sellers in a commercial center also appeared to have an impact on local fuel prices. Every additional business that sold energy in a community was associated with an average 1.7 KES per liter drop in fuel prices. As with the result for the presence of tarmac roads, this estimate is somewhat ambiguous, but again provides suggestive evidence that increasing the competitiveness of energy markets can have a positive impact on rural fuel prices.

CHAPTER 5

HOUSEHOLD ENERGY USE

The subject of household energy use in developing countries has garnered significant attention from both academics and policymakers. Of particular interest in the literature are issues regarding how much the poor spend on energy and how their energy choice and purchasing decisions are made. A basic pattern observed across countries worldwide is that poor households tend to spend a significantly higher percentage of their income on fuel than wealthier ones. Some studies in Sub-Saharan Africa have found that poor households can spend over 20 percent of their income on fuel (World Bank, 2005). At the same time, poorer households consume relatively small amounts of modern, commercialized fuels (petrol, diesel, LPG). In many cases, poor households do not buy any modern fossil fuels at all (Bacon, et al., 2010).

This dichotomy – that poorer households spend a higher percentage of their income for inferior energy products – has raised questions about how to decrease the burden of energy purchases on poor consumers. However, in order to answer this question, the details of how households make energy consumptions decisions must first be understood. For example, for governments seeking to reduce energy subsidies the negative welfare effects on poor households are an important consideration. But if poor households do not spend significant amounts of their energy budgets on modern fuels, then subsidies would not be helping the poor in the first place. To address this problem, detailed information is needed about household consumption behavior and decision-making processes. In the following sections we briefly summarize some of the current evidence on household energy consumption patterns throughout the developing world.

5.1 Energy Ladder Hypothesis

The early literature on energy use in developing communities frequently noted distinct consumption patterns across different socio-economic groups. In Nepal, Bajracharya (1983) found that energy fuel types differed according to the social class of the household. Households of higher social class consumed more commercially traded fuels than did households of lower social class. Similarly, in a study based in Kenya, Barnes, et al. (1985) found that fuel consumption mixes were dependent on the household's level of integration into the market economy. More integrated, and thus richer, households used petroleum products at higher rates than more did household less highly integrated into the market economy. Alam, et al. (1985) reported that household fuel decisions across India corresponded directly with income levels. Higher income households were much more likely to choose petroleum-based commercial fuels over biomass resources across a wide set of communities. Overall, the early literature on household energy use supported the concept that energy use was strongly linked to a household's socio-economic status.

From these early studies emerged the energy ladder hypothesis of household fuel choice. Under this theory, households behave like a rational consumer, choosing cleaner, efficient, and more expensive energy sources as their incomes increase. While poor households will burn biomass in the form of wood, charcoal, and crop residues, wealthier households will opt to consume kerosene, LPG, and electricity. In this model, firewood, charcoal, and crop reside are inferior economic goods thus implying that households will switch away from them as incomes rise. Fuel switching is an integral part of the energy ladder, as a move “up” to a new fuel implies a move away from the previously consumed fuel. The energy ladder concept was largely assumed in the early literature of developing world energy consumption. More recently, however, attention has been devoted to testing the validity of this assumption.

An early examination of the energy ladder hypothesis came from Hosier and Dowd (1987). Applying a multinomial logit approach to a data set from Zimbabwe, they studied the factors that influence households fuel choices. Their results largely supported the energy ladder formulation as they found that households do move away from wood into kerosene and then electricity as incomes rise. However, Hosier and Dowd also identified several other factors that are important in determining household fuel choices besides income. Specifically, household size, firewood scarcity, and fuel prices all had a significant impact on which energy sources a household chose to consume.

While Hosier and Dowd’s findings lent credence to the energy ladder approach, more recent studies have found that the impact of income on fuel choice is weaker than earlier assumed. In a review of global firewood use, Arnold, et al. (2006) found that estimated income elasticities for firewood in developing countries were very low and frequently insignificant. In a few cases, they even found that firewood operated as a normal good with positive income elasticity.

Similarly, Cooke, et al. (2008) found that fuelwood demand in developing countries was income and own-price inelastic. Few households substituted away from firewood despite policymakers' efforts to encourage modern fuel use. Wood remained an important source of fuel for households even at the upper end of the income spectrum.

More recently, Hiemstra-van der Horst and Hovorka (2008) sought to assess the energy ladder by investigating household energy use in Botswana. Their findings suggest that while energy use varies between high and low income households, the transition from "poor" fuels to modern fuels is more complicated than a simple switching model. Indeed, they found that the labeling of firewood and charcoal as "poor" fuels itself to be an oversimplification of reality, since wealthier households continue to use biomass fuels for basic energy needs even as their incomes rose. These households instead often *supplement* their energy consumption with more modern fuels, rather than *replacing* biomass outright.

Furthermore, some studies have found that fuel adoption is not a unidirectional process. Households that have previously adopted a more modern technology may switch back to traditional fuel sources. Wickramasinghe (2011) found that households in Sri Lanka would often abandon LPG and move back to fuelwood consumption in response to higher market prices for LPG. Maconachiea, et al. (2009) observed households outside Kano, Nigeria increasing their consumption of biomass after having previously used petroleum-based products. The change in behavior was in response to increasing petroleum prices, which made fuelwood and charcoal a more attractive option.

The above evidence suggests that while income plays a role in households' decisions to use modern fossil fuel-based energy sources, the idea of an energy ladder does not accurately describe this transition. Instead, households appear to be adopting new energy sources that are only a partial substitute for traditional fuels (Van der Kroon, 2013).

5.2 Energy Stack Hypothesis

As the literature has become more critical of the energy ladder model of household fuel consumption, more recent literature on household energy choice has adopted the concept of an energy portfolio or energy "stack." Under the energy ladder hypothesis, low-income households begin at the bottom of the ladder where they consume biomass sources of fuel, primarily firewood and crop residues. Then, as their income rises, they replace these fuels with more efficient and expensive fuels, which in turn are finally replaced by LPG and electricity. In contrast, the energy-stacking model suggests that households add fuels to their consumption basket as their income rises without necessarily replacing the previously used fuel sources. As a result, a household that uses LPG as a cooking fuel may also continue to burn firewood or charcoal. Figure 5.1 gives a visual representation of these competing models.

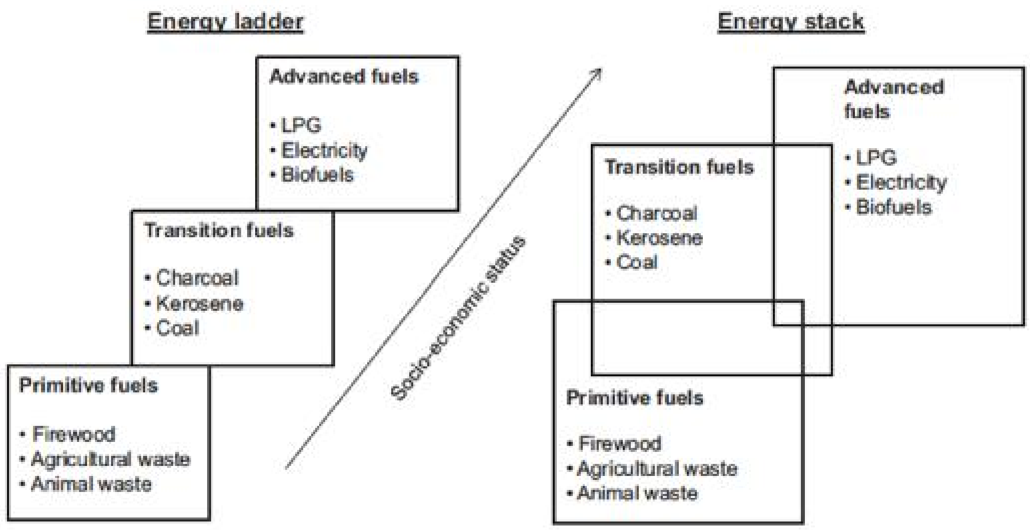

Figure 5.1: Energy Ladder Compared to Energy Stack
Source: van der Kroon (2013)

Foley (2005) suggests that energy stacking occurs because households do not change their fuel preferences; rather they acquire new fuel demands. For example, very poor households mostly demand energy for cooking and lighting and thus they can rely on biomass to adequately fill these needs. But, as incomes increase, households gain access to new technologies such as a generator or household appliances. These new technologies will often require a new energy source for their operation which subsequently diversifies a household's fuel requirements. However, for their basic needs, traditional fuels will continue to be consumed with more advanced fuels being added as living conditions improve.

Masera, et al. (2000) takes a slightly different viewpoint from Foley. Rather than viewing energy adoption as a response to completely new technologies, they find that households often use multiple fuels for the same domestic purpose. For example, a wealthier household may purchase an LPG stove for cooking and subsequently begin to purchase that fuel type. However, it is rare that households will completely abandon their old traditional stove and will instead operate both simultaneously. As such, wealthier households will often use multiple fuels for a single purpose, such as lighting or cooking. Complete abandonment of traditional fuel sources occurs only gradually or not at all.

There have been several efforts to explain the motivation behind the so-called energy stacking behavior. First, Davis (1998) explains that using multiple energy sources is a natural response to variable incomes. Households in developing countries often have uncertain and irregular income streams tied to agriculture or seasonal work, and so will not reliably be able to afford more expensive fuels. By using multiple fuels to meet their energy needs, households are able to improve their energy security and hedge against income shocks. Using our previous example, if a household is unable to afford LPG for a time due to a bad harvest, they will maintain the ability to easily switch back to a traditional cook stove and biomass energy.

Second, Hosier and Kipondya (1993) argue that problems in petroleum product supply chains are primarily responsible for households' fuel stacking behavior. As noted in the discussion above of commercial centers in Western Kenya, supplies of modern energy to rural areas are frequently disrupted. Due to this uncertainty of fuel access, households may naturally consume multiple fuels in case one source of energy is temporarily cut off. Additionally, they note that energy prices in rural areas are typically high and variable. These price fluctuations increase the chance that an energy source may become unaffordable in the short run.

Lastly, Maser, et al. (2002) find that cultural factors also play a role in energy stacking behavior. Tradition and taste preferences may make fuelwood an indispensible part of cooking in certain cultures. So, while a household may be able to afford and have access to more modern fuels, they may choose not to use them in response to tradition or social factors.

Overall, the energy-stacking model has gained support in the literature. However, there remain a few points of contention. First, the exact shape of the curve between income and the number of fuels used by a household is unclear. Heltberg (2005) finds an inverted "U" relationship between income and the number of fuels consumed by households. As very poor households increase their incomes, they demonstrate increased fuel stacking behavior. However, at upper ends of the income spectrum, households reduce the numbers of fuels they use, opting instead to exclusively consume modern forms of energy. Conversely, Mirza and Kemp (2009) find that households do not switch away from biomass fuels even at high incomes. They find that households place a high premium on energy sources that are in close proximity to them. Thus, even wealthy households that are distant from sources of modern fuels are likely to continue to use biomass for their energy needs.

Second, the specific drivers behind multiple-fuel use by households continue to be debated. Examples of factors that have been identified as important in determining fuel use are education, gender, household size, and proximity to fuel sources (Hosier and Dowd, 1987; Heltberg, 2005; Pundo and Fraser, 2006). All of these factors have been found to be important in some geographic contexts but not in others. However, despite these points of ambiguity, the recent literature seems to have reached a consensus in favor of the general energy-stacking model.

5.3 Western Kenya Household Survey

We now turn to evaluate the energy-stacking model in the context of our case-study country, Kenya. By examining energy use patterns in Western Kenya, we can see if households in the region exhibit behaviors similar to those described in the literature. To this end, we use a detailed household data set collected from the area around Kisumu, Kenya to see if wealthier households adopt modern fuels at higher rates than poorer households while also maintaining high levels of biomass consumption.

Household-level data on energy use and consumption were collected as part of a detailed household survey conducted in Western Kenya from September 2011 to May 2012. This survey was conducted by Julia Berazneva[16] and her field team from the same five research blocks – Lower-Nyando, Mid-Nyando, Lower-Yala, Mid-Yala, and Upper-Yala – as the commercial center survey data described above (see Figure 3.1). Within each 10x10 km block, three sub-locations (Kenya's lowest administrative unit) were chosen at random to be surveyed. Subsequently, a list of villages in each sub-location was compiled from which three villages were chosen at random, one from each sub-location. Finally, a list of households was then gathered for each village from which twenty-one households were randomly chosen for an

[16] PhD Candidate in Dyson School of Applied Economics and Management, Cornell University.

interview and survey. In total, the survey contacted 315 households – twenty-one households from each of the three villages in each of the five research blocks.

The household data were collected in two rounds in order to capture the two distinct cropping seasons that are present in some of the research blocks. The first round took place from October 2011 until January 2012. Information was collected on household production activities during the "long rains" (March to May) in 2011, including income sources, resource endowments, labor availability, and socio-economic characteristics such as household composition, educational background, and labor market participation. The second interview round took place from February 2012 to May 2012 and entailed re-visiting the same households. The second round of the survey collected information on household production activities during the "short rains" (October to November) in 2012, household assets, knowledge of climate change, as well as residential energy use. The first round surveyed 315 households while the second round reached only 313 households due to household migration and refusals.

This study uses data collected from both rounds of the survey, but focuses primarily on the domestic energy use data collected in the second round from February to May 2012. The following section examines this data in the context of the analysis above of commercial centers in Western Kenya as well as the previous literature on household fuel choice. In particular, we examine the data for evidence regarding the current theory of energy stacking. To do this, we analyze total household expenditures on fuel and how both expenditures and fuel choice vary with income.

5.3.1 Households

Our study sample includes the 313 households that were randomly selected from the five survey regions and that were interviewed in both rounds of the survey. For the purposes of the study, a household was defined as a group of individuals living in the same compound who share a common source of resources and income. Summary statistics are given in Table 5.1.

Table 5.1:Household Demographics

	Average	Minimum	Maximum
Head of Household Age	51	20	90
Household Size	6	1	13
Head of Household Years of Education	6.8	0	18
Household Income	147,000	0	3,674,000
Dependency Ratio	1.1	0	6
Percent Married	77%	-	-
Percent Male	80%	-	-

On average, each survey household is comprised of six people, for which the head of household is 51 years old and has 6.8 years of education. This is approximately equivalent to a partial primary education, but depends on year the participant was born. For individuals born before 1978, primary school lasted seven years while for individuals born after this year primary school lasted for eight years. Heads of households are 80 percent male and 77 percent are currently married (the remainder are either separated or widowed, while less than one percent were never married at all). Average annual household income is 147,000 KES[17], but is quite variable with a few households reporting no income at all. Total household income was calculated by combining self-reported data from several discrete income sources. These include income from crop sales, animal production, off-farm or business profits, and remittances. The average dependency ratio (defined as the number of individuals below the age of 15 or above the age of 65 divided by the number of working age adults) is 1.1.

5.3.2 Fuels Used by Households

Now that we have a basic demographic picture of our households, we turn to household fuel use. To begin, we look at the percentage of households in our sample that use each major fuel type. These fuel categories differ slightly from the groups that were presented in the commercial center study. First, crop residues, which include maize stover, maize cob, animal manure, and other biomass, is a new fuel category. These materials are rarely traded in the commercial centers as an energy source and so were not captured in the commercial center survey. However, it is an important source of energy for households, but is primarily either self-collected or purchased (bartered) from neighbors. Second, petrol and diesel have been combined into one fuel category. This is a consequence of the survey construction, which asked about these two fuels in the same question. Therefore, petrol and diesel's usage rates cannot be distinguished from one another. However, this distinction is not particularly important as households typically use both these fuels

[17] This translates to $1,764 (US) at the KES-USD exchange rate on Feb 1st 2012.

for the same purposes of transportation or as fuel for generators. Last, electricity use is included in the study as an energy source. The electricity category includes grid electricity, solar powered electricity, and battery powered electricity. Each of the electricity categories comprise about a one-third of the total electricity user sample. While electricity delivery systems are inherently different than other fuel types, it is important to include them in examining the energy stacking model.

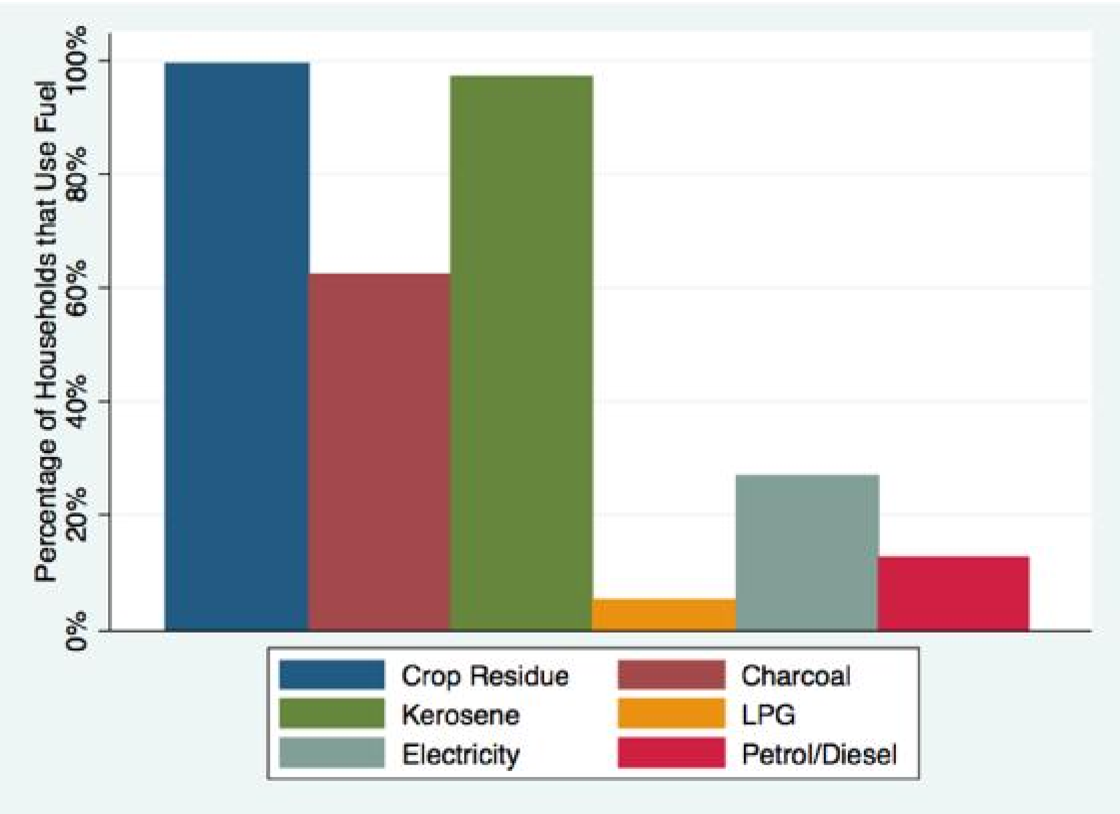

Figure 5.2: Percent of Households Using Fuel (n = 313)

Figure 5.2 presents the percentage of households in the sample that reported using each fuel type in the past year (2011). It is clear from the graph that three fuel types – crop residue, charcoal, and kerosene – dominate household fuel use. Crop residue and kerosene are used by over 90 percent of households with charcoal being consumed by just over 60 percent. The next most common energy source is electricity, which is used by 26 percent of the households. Last, 12 percent of households use petrol or diesel and only 5 percent use LPG. These results are largely consistent with our previous findings in Chapter 3 regarding the frequency that fuels are sold in commercial centers (see Figure 3.2). Kerosene is by far the most commonly used and sold fuel in the commercial center survey and is also consumed by nearly all households. Conversely, petrol, diesel, and LPG are sold by relatively few stores and are also consumed by few households. The only fuel that does not appear to match our previous result – leaving aside crop residue which is not formally sold in commercial centers – is charcoal, which is consumed by well over half of all households but is only available for purchase from 22 percent of energy sellers. This suggests that many charcoal transactions occur outside of the formal market place and were not captured by our commercial center survey.

The above discussion gives a summary of overall energy use in the sample. However, in order to test the energy-stacking hypothesis, it is necessary to examine how fuel use changes across different socioeconomic groups. To do this, we split the data into five roughly equal income quintiles based on self-reported household earnings. Earnings were calculated by aggregating income from the several disparate sources mentioned previously. While there may be some difference between reported income and socio-economic status (due to other sources of wealth), we hope earnings will provide a reliable proxy. The income quintiles are detailed in Table 5.1 below.

Table 5.1: Income Quintiles

	1st	2nd	3rd	4th	5th
Average Annual Income (KES)	14,500	40,800	83,400	144,600	459,800
Minimum Income (KES)	0	27,000	60,800	111,100	180,400
Maximum Income (KES)	26,500	60,200	110,600	180,000	3,627,000
Observations	63	63	62	64	61

Note: As of the exchange rate on January 1, 2012, 10,000 KES = $120 (US), and 100,000 KES = $1,196 (US).

As is evident from Table 5.1, the five income quintiles are more tightly bunched at the lower end of the income distribution. This reflects the fact that the household income distribution is skewed to the right; the mean of the data lies at 147,000 KES while the median income lies at 80,000 KES. For this reason, our top income quintile contains a much wider range of incomes than the bottom quintiles. Additionally, the highest reported income level of 3,627,000 KES is a significant outlier, being more than three times the next highest reported income. The proceeding analysis was conducted with and without this observation in order to ensure that the outlier was not solely driving any results. While aggregated numbers changed slightly with the outlier's exclusion, the overall story remained the same. Therefore, all reported figures include the full sample unless noted otherwise.

We can now turn to investigating the differences between our income quintiles. We begin by reporting the spread of the income quintiles over their physical location across the five survey blocks: Lower-Nyando, Mid-Nyando, Lower-

Yala, Mid-Yala, and Upper-Yala. This is a useful as it allows us to determine if our households are clustered together by socio-economic class. For example, if all rich households live in the same region, observed differences in energy consumption patterns could be a result of geographical factors rather than a result of differences in income.

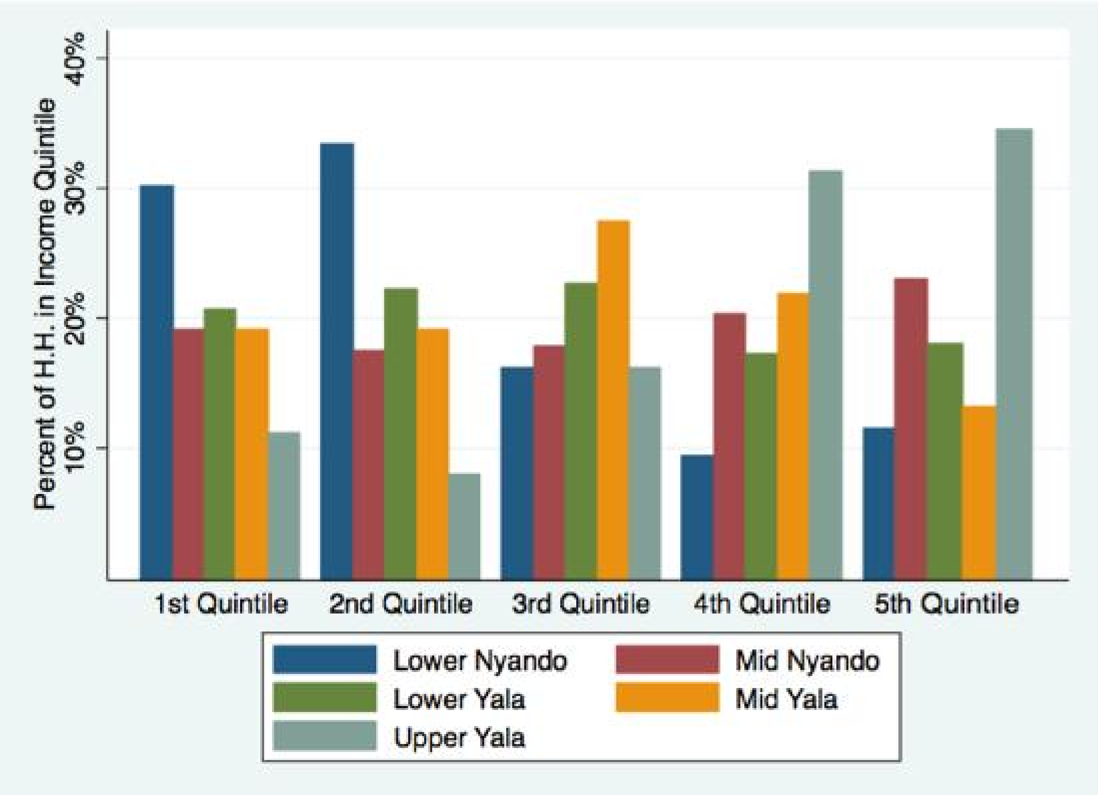

Figure 5.3: Income Distribution by Geographic Location

Figure 5.3 shows how income is split over our five survey blocks (see Figure 3.1). On average, Lower-Nyando and Upper-Yala occupy two ends of the income distribution. Lower-Yala is significantly poorer than the overall sample while Upper-Yala is significantly richer. This may go some way to explaining the large gap in fuel sold between these two blocks that was observed in Chapter 3 (see Figure 3.4). If households in Lower-Nyando are unable to afford commercial fuels then differences in regional demand may be a function of income. However, high quantities of liquid fuel were also sold in Mid-Yala and its households are of only average wealth. Meanwhile, Mid-Nyando and Lower-Yala appear to be roughly evenly split between the five income quintiles, and both also reported average quantities of fuel sales. Overall, despite having slightly poorer households in Lower-Nyando and slightly richer households in Upper-Yala, all income groups are represented in each block. This indicates that differences between quintiles will not be driven by physical location, and will instead be indicative of the different energy decisions made by households in different socio-economic groups.

We can now examine how fuel usage differs across the different income groups. Figure 5.4 presents the household usage rates of the same six fuels that were presented in Figure 5.2 over our income quintiles.

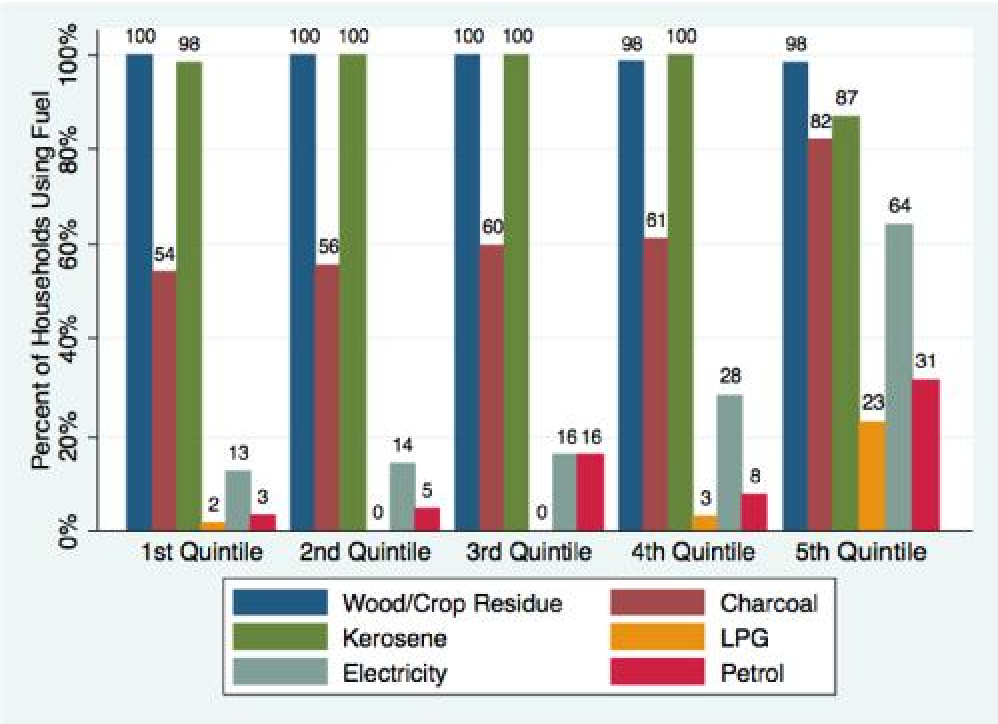

Figure 5.4: Household Fuel Use by Income Quintile

There are several significant patterns in fuel usage rates among the five income groups. First, the usage of crop residues does not change at all as income rises. Even in the top quintile of earnings, 98 percent of households consume crop residues as fuel. This pattern nearly repeats itself with kerosene, as 87 percent of the top earners use kerosene in their homes. The other four forms of energy – charcoal, LPG, electricity, and petrol/diesel – all show signs of increased use at higher incomes. Charcoal is used by 54 percent of households in the lowest income quintile, rising steadily to 82 percent usage by households in the top quintile. Electricity is used in small amounts throughout all income groups, but rises significantly at the top quintile to over 60 percent. However, this rise masks the change in composition of the electricity category. Usage in the bottom three quintiles is mostly comprised of battery and solar sources, while the top two quintiles use mainly electricity from the grid. . Petrol and diesel follow a similar pattern but only rise to a 31 percent usage rate in the top income quintile. LPG is used hardly at all in the bottom four income groups with a sharp increase to 23 percent usage in the top category. This jump in the last group indicates that LPG may be the last energy source to become affordable and be adopted by households.

Figure 5.4 presents evidence that the energy stacking hypothesis is well suited to describe household energy use patterns in our sample households. At low income levels, household primarily use three fuels, crop residue, kerosene and, to a lesser extent, charcoal. Then, as incomes rise, the number of fuels being used by households also rises. In the poorest group, the average household uses 2.7 sources of energy while an average household in the top income group uses 3.9 different sources. In particular, electricity shows the greatest increase in adoption with rising incomes, as it moves from being used by only 13 percent of households in the lowest income quintile to 64 percent in the highest. Crucial, however, is the point that even at the highest levels of income, crop residues and kerosene are used ubiquitously. This suggests that there is little outright fuel switching occurring among our sample households. Instead, households appear to be adding more energy options as their income rises. Even the wealthiest households that have invested in LPG and electricity continue to use kerosene, charcoal, and crop residues. This result fits very well with the fuel use pattern predicted by the energy stack hypothesis.

There are several other interesting things to note from Figure 5.4. First, charcoal use has a positive correlation with income, with the largest jump in usage occurring at the highest income quintile. This suggests that charcoal is not an inferior good, and may be considered a desirable cooking fuel. Second, nearly all households, even in the lowest income group, use kerosene. This suggests that kerosene may no longer be considered a "transition" fuel, but may instead be treated as a household necessity. This is supported by the observation that kerosene is by far the mostly common liquid fuel sold in commercial centers throughout the survey areas.

5.3.3 Fuel Expenditures

Having looked at what types of fuels households are using, we can now examine how much these same households are spending on fuel. Together, all 313 households spend approximately 756,150 KES per month on all energy sources, or about 2,415 KES each. This is equivalent to a $9,073 US monthly total or a $29 US monthly expenditure per household. However, as would be expected, the amount of money spent on fuel is not evenly split among households at different income levels. Figure 5.5 below gives the *avergae* monthly amount that is spent on all fuels in each income quintile.

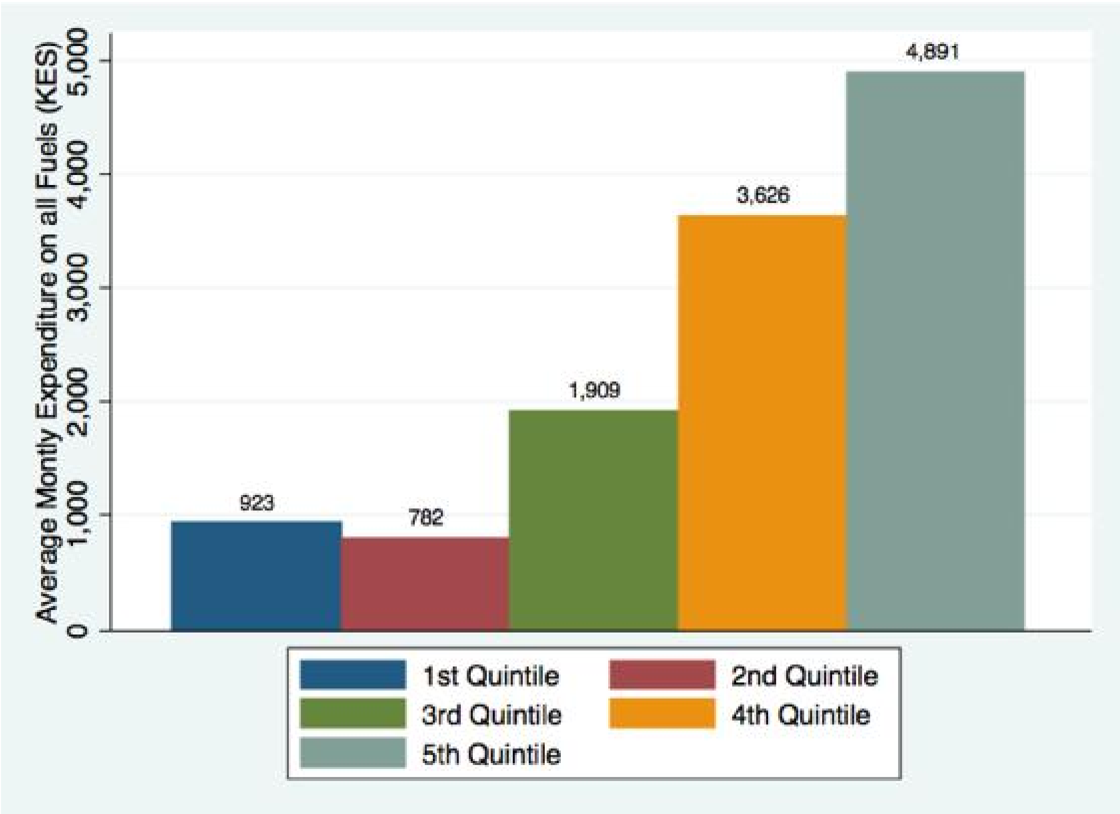

Figure 5.5: Average Expenditure on Fuel by Income Quintile

Figure 5.5 shows a large increase in energy expenditure from the bottom to the income distribution to the top. The bottom two income categories spend roughly the same amount on energy at around 850 KES per household. Strangely, the lowest quintile spends approximately 150 KES more per month than the penultimate group (this may just be an artifact of this particular data set). From the bottom two groups, expenditures on energy increase sharply with income. The third income quintile spends double the amount as the lower two, while the fourth spends roughly double the third. Expenditure increases then seem to level out slightly as the top income quartile spends only 36 percent more on fuel than the fourth quintile. Overall, total monthly expenditures on energy by the top income group are approximately six times greater than either of the bottom two quintiles.

The apparent non-linearity in the growth of energy outlays with income suggests that expenditure growth is being driven by the addition of new, more costly fuels, rather than a steady increase in the consumption of cheaper fuels. That is, rather than consuming more crop residues or kerosene as income rises, households instead appear to consume new forms of energy while maintaining their previous consumption level of less expensive fuels. To further examine this, Figure 5.6 presents monthly expenditure on each fuel type over income quintiles.

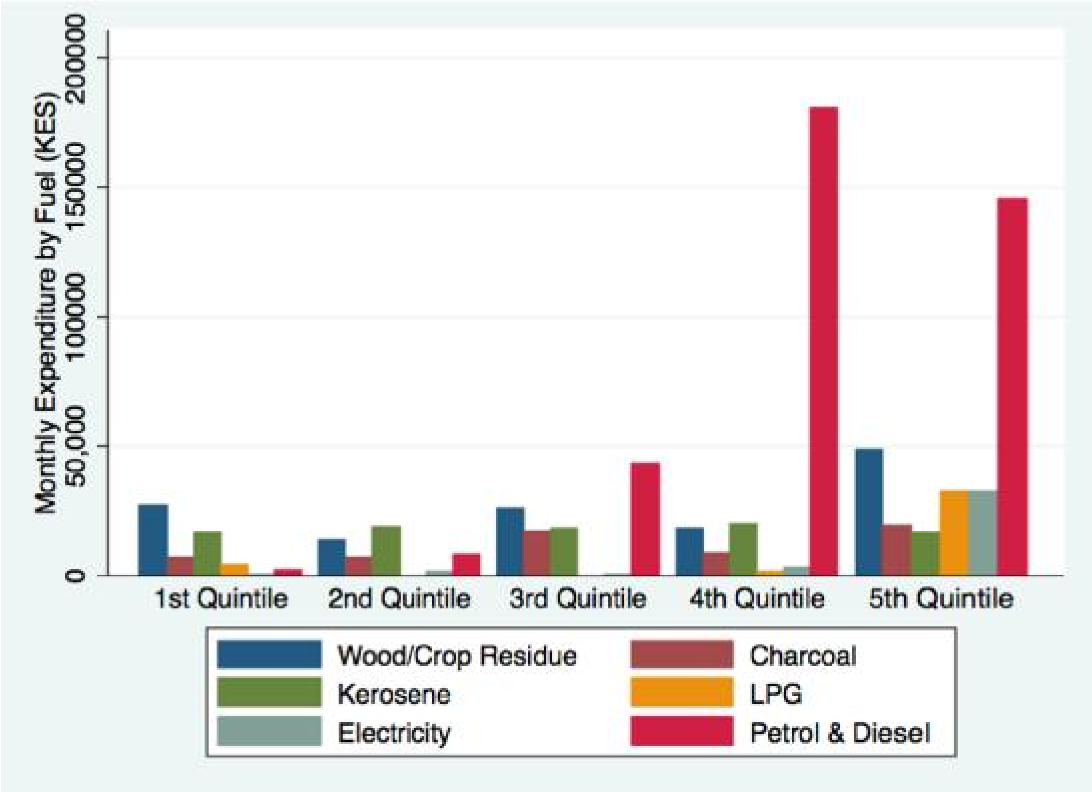

Figure 5.6: Total Expenditure on Each Fuel by Income Quintile

Several patterns become clear from the data presented in Figure 5.6. First, expenditures on crop residue, kerosene and charcoal stays relatively constant across the income quintiles. Expenditures on kerosene, in particular, are almost entirely flat, while those for charcoal and crop residue exhibit a slight increase among the top income group. Second, expenditures on petrol and diesel, electricity, LPG all demonstrate sharp increases as income rises. In particular, petrol and diesel expenditures show a very large increase from the second group to the fourth group. The increased spending on these two fuels is largely responsible for the doubling of total fuel expenditures between these quintiles shown in Figure 5.5. Interestingly, spending on petrol and diesel decreases moving from the fourth to fifth income quintile (again, this may simply be an artifact of the data and not reveal some underlying trend). However, this decrease in spending is more than made up for by increased expenditures on LPG and electricity. Indeed, LPG and electricity account for very little of total expenditures until the top income group where there is a large jump in spending on these high-end energy sources. Last, in general, the top income quintile spends more on every energy category than the lower income households. This includes “traditional” fuels such as crop residue, charcoal, and kerosene.

Another important part of total fuel expenditures are the prices that are paid by households for each fuel type. In Chapter 3, we examined how poorer households often pay the highest per liter prices for liquid fuels. We can now examine this result using the household data. Figure 5.7 below shows the prices paid per liter for each liquid fuel (petrol and diesel combined).

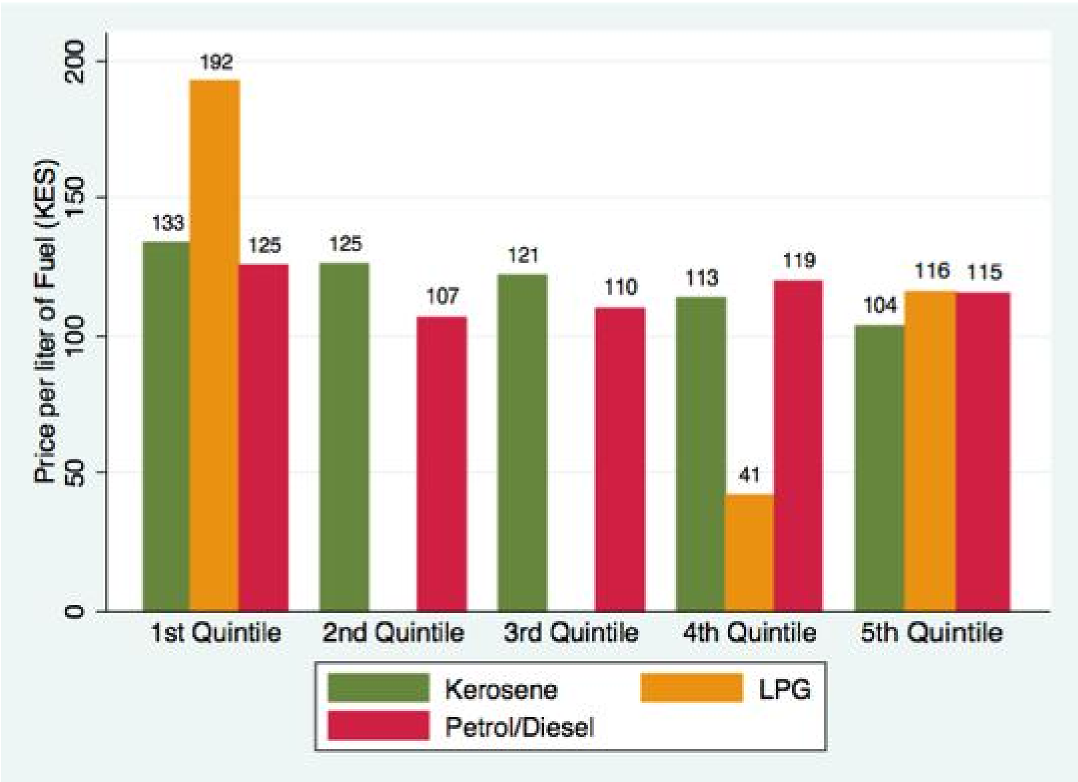

Figure 5.7: Prices Paid per Liter by Income Quintile

The first thing to note in Figure 5.7 is that the per liter price of kerosene exhibits a clear downward trend as incomes rise. The lowest income quintile spends an average of 133 KES per liter of kerosene while the highest income quintile spends only 104 KES per liter, a decrease of 22 percent. This lends support to the case that the poorest households are most affected by problems in the fuel distribution network. LPG and Petrol/Diesel offer more ambiguous evidence. LPG is purchased at a very high per liter price by the lowest income quintile, and then drops sharply before rising again in the fifth quintile. However, due to the very small number of LPG buyers in the quintiles below the fifth, the per liter prices are not robust as they depend on only one or two observations. Similarly, petrol and diesel prices do not show a clear trend as incomes rise. The per liter price is highest in the lowest income quintile, but drops in middle income households before rising again at the top of the income spectrum. Again, however, the low usage rates of petrol and diesel at low income levels make the price paid per liter dependent on a few observations.

Overall, this evidence is consistent with the theory that increased energy expenditure is being driven by additions of new energy sources to household consumption rather than increased expenditures on traditional fuels. This also fits nicely with the energy stacking hypothesis. Wealthier households actually spend more on traditional fuel sources even as they add new fuels to their portfolio.

A question that arises from Figure 5.6 is what is driving the very large increases in petrol and diesel expenditure beginning at the third quintile. One plausible explanation, as suggested by Foley (2005), is that households in these income brackets are acquiring technologies that require modern energy sources to operate, leading to discrete changes in fuel consumption behavior. Indeed, this may to be the case in our data. In Chapter 3, Figure 3.5 suggested that consumption for both petrol and diesel was primarily driven by transportation. Thus, we can investigate whether increased expenditure on these fuels by households is correlated with the modes of transportation available to each income group. To do this, Figure 5.8 reports the number of motorcycles or cars owned per household in each quintile.

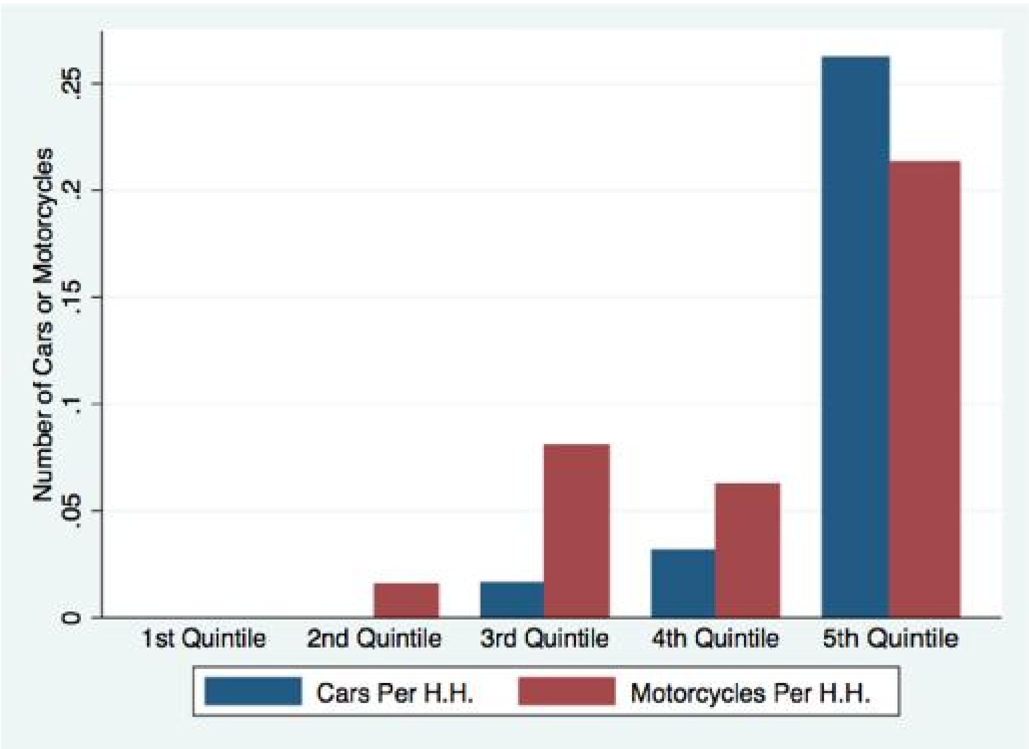

Figure: 5.8: Number Cars and Motorcycles Per Household by Quintile

This figure shows a steady increase in the number of vehicles per household as income rises. Motorcycles are the first to be adopted in the second quintile, as they require less capital investment and fuel to operate. Motorcycle ownership generally increases with income until there are 0.2 motorcycles per household in the top income bracket. Cars first appear in the third income quintile and show a dramatic increase to over 0.25 cars per household at the top income group.

Vehicle ownership rates and expenditures on petrol and diesel thus appear to be correlated. The first appearance of cars and motorcycles in significant numbers occurs in the third quintile, which corresponds to the first jump in petrol and diesel expenditure seen in Figure 5.6. However, there is no explanation for the extremely large increase in petrol and diesel expenditure in the fourth quintile. Car ownership rates in the fourth group are only modestly higher than the third quintile and motorcycle ownership rates are actually lower. Overall, though, vehicle usage appears to offer a strong explanation for the large increase in petrol and diesel expenditure at high income levels and lends support towards Foley (2005) assertion that new technologies drive new fuel demands.

To this point we have only examined total expenditure differences across groups, independent of how these expenditures compare as a share of household income. While richer households may be spending absolutely more on energy than poorer households, they may be spending a similar or smaller proportion of their total income. Conversely, it is possible that new technologies, such as cars and LPG stoves, encourage a household to spend more of their total income on fuel. To examine this dynamic, Figure 5.9 reports the percentage of total household income that is spent on fuel over the five income quintiles.

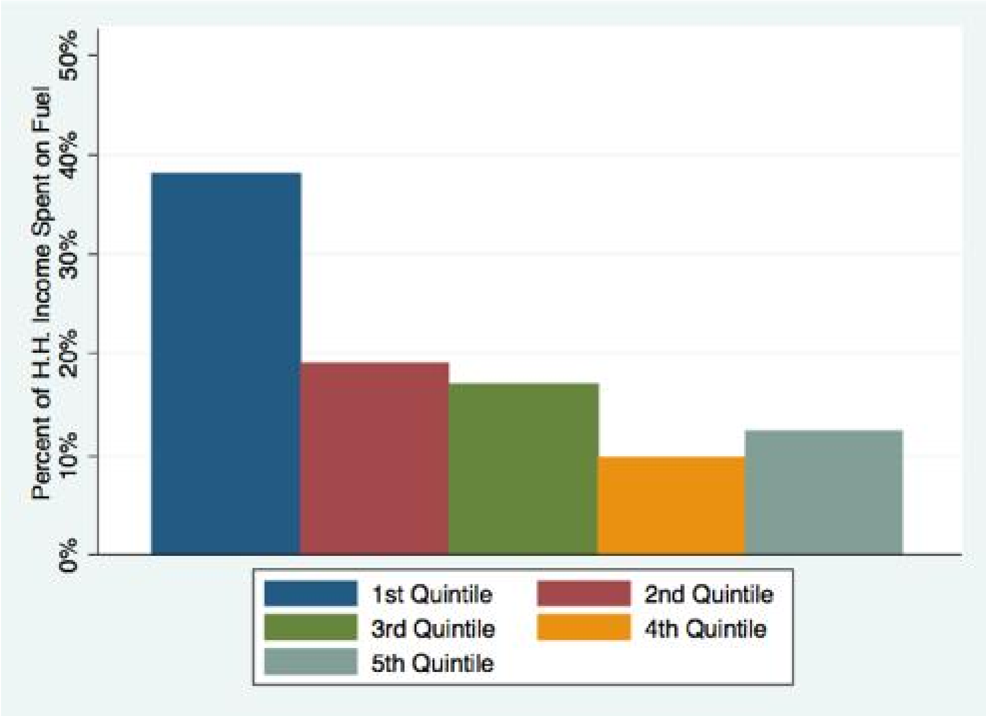

Figure 5.9: Percent of Household Income Spent on Energy
Note: Households that reported zero income are not included in this figure.

This figure shows a clear negative relationship between total household income and the share of income devoted towards energy. The poorest households spend 38 percent of their total income on energy, by far the largest share of any group. Compared to evidence in the previous literature this is a very high percentage, almost twice the normal 20 percent estimate of how much poor households typically spend on fuel (World Bank, 2005). It is possible that difficulties in calculating income for very poor households are responsible for our high estimate. For example, if a household has irregular income throughout the year, then some significant but infrequent earnings may not have been captured in the household survey. This would cause an underestimation of total household income and therefore an overestimation of the percentage spent on energy.

The second quintile spends 19 percent of their income on fuel, a sharp drop from the first. The percent of income spent on energy then steadily decreases (with a slight increase between the fourth and fifth quintile) as incomes rise. Overall, it is clear that higher income households, on average, spend much less of their income on fuel than poorer households. This is despite their purchasing a greater variety of fuels at higher prices than lower income households.

Additionally, it is important to note that the estimates above likely represent an underestimate, perhaps a significant underestimate, of the total cost of fuel consumption. Most households spend significant time collecting biomass from their land and the surrounding area for their home consumption. The time spent collecting fuel presents a significant cost to the household as it absorbs available labor that could be spent on other productive activities. This is particularly true for women who are disproportionally responsible for fuel collection (Karekezi, et al., 2004).

Regardless of the precision of our estimate for poor households, it is clear that energy is an important component of household expenditures. This is especially true for the poorest households in our survey. For these consumers, small price increases in fuel prices can indeed pose a large burden. Kerosene prices are particularly important, as this is the main commercial fuel widely purchased by low-income households. For these households, the supply chain inefficiencies and associated price increases outlined in Chapter 3 can have serious negative welfare impacts.

5.3.4 Sources of Fuel

Now that we have examined the fuels households purchase and how much they pay for them, we examine where consumers purchase their fuel. Figure 5.9 reports the location where survey households purchase their fuel in four categories. The first category is for households that purchased their fuel from a neighbor in their village. These transactions are typically for crop residues and may involve bartering rather than cash exchanges. The second locational category is the village market, which is defined as the closest commercial center to the survey village. The third category is the district market, which is defined as any commercial center that is not the local market. Typically, the district markets are larger commercial centers and fall outside of the survey area. In some rare cases the district market is Kisumu. The last locational category is a petrol station for any household that was able to purchase their fuel from a gas pump.

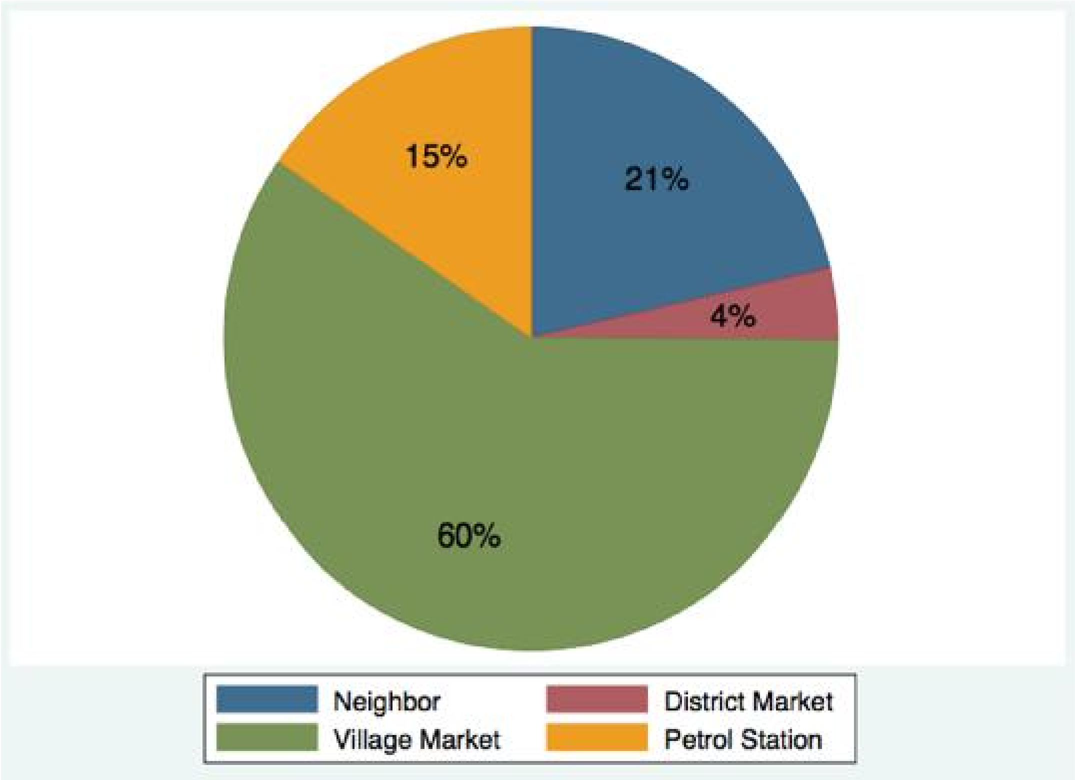

Figure 5.10: Location Where Households Purchase Fuel

Figure 5.10 illustrates that households overwhelmingly source their fuel from their immediate vicinity, including from both neighbors and the local village market. Relatively few households are able to purchase fuel from a petrol station, which reflects our previous findings that rural areas are underserved by efficient oil marketing companies (OMC). Also, the very low percentage of households that purchase fuel from a more distant district market indicates that households do not often purchase fuel from distant commercial centers. This finding largely supports the results reported in Mirza and Kemp (2009) that households place a premium on fuel sources close to them. The proximity to fuel sources remains an important factor even for wealthy households

This result underlines the importance of improving fuel delivery efficiency to rural areas. Households are often unable or unwilling to travel significant distances for cheaper fuels available from more efficient retailers and thus are largely at the mercy of local market prices. Relatively few households have access to the efficient and cheaper petrol stations, further increasing the price paid by consumers. Additionally, the frequency at which fuel is purchased from petrol stations and from district markets falls at lower income levels. This further points to the difficulty poor households have in accessing reasonably priced fuel sources.

5.4 Further Analysis

It would be logical to examine the household data in a regression analysis similar to the concluding results in the Chapter 3. The previous literature has explored household fuel choice decisions through estimation of a multi-nominal logit model, which would be a natural choice for our problem and data. Indeed, we attempted to use this framework to examine the determinants of household fuel choice, including as independent variables, factors such as income, age, gender, and education. Unfortunately, the relatively low sample size of 313 households and the inherently noisy nature of the survey data made this exercise inconclusive. Most estimated models were unable to produce consistently reliable estimates, and when estimates were obtained they were typically statistically insignificant. While future research in this area would be desirable, a larger sample size would likely be necessary to successfully estimate these choice models.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Rates of energy consumption in East Africa remain among the lowest in the world. Limited by rising prices and poor access to modern fuels, energy-constrained communities face the prospects of stunted economic growth. Households in these largely rural areas are frequently restricted to use biomass as their sole source of energy. The use of biomass as a primary energy source is often inefficient, unhealthy, and has negative environmental impacts. For these reasons, enabling poor consumers to adopt modern, commercial fuels is an important policy objective (notwithstanding their acknowledged limitations).

The research reported in this thesis examines how inefficiencies in the energy distribution network contribute to limiting households' access to modern fuels. We begin by examining the macro-economic conditions that constrain fuel access. We then successively narrow our focus, moving first to commercial centers and their role in supplying affordable energy to consumers, and then finally to rural households and the constraints on their energy consumption patterns. In this way, we attempt to provide a comprehensive and integrated picture of rural energy markets in developing countries.

Our research begins by examining the overarching fuel distribution system that delivers fuels from international markets to consumers. First, we identify numerous government policies that contribute to high prices and limited energy access in East Africa. These include poor regulations, underdeveloped infrastructure and inefficient market structures. More specifically, we find that governments regulate energy markets primarily through price controls (subsidies or caps), which have the potential to lower fuel prices to consumers, but these policies also create distributional inequities and also tend to have the unintended consequence of reducing fuel availability in rural areas. Additionally, we establish that poorly developed networks of pipelines, railroads, and paved roads serve to increase transportation costs and fuel prices, which then limit access to poor rural households. Finally, noncompetitive fuel distribution markets frequently lead to higher overall fuel prices and underinvestment by oil marketing companies (OMC) in sparsely populated areas, in turn to the detriment of rural consumers. These findings largely confirm and are drawn from the previous literature, most notably Bacon (2001), Bacon and Mattar (2005), and Kojima, et al, (2010).

Having identified these regional market inefficiencies, we use rural Kenya as a case study to further examine their impacts on consumers. Drawing on a detailed data set gathered from 56 rural commercial centers from Western Kenya, we are able to characterize rural energy markets in the region. We summarize the quantities, prices, and sources of each fuel traded by several groups including business sellers, business users, and transporters. Overall, we find that significant quantities of modern fuels are already used in rural areas. However, the market employs each fuel for a distinct purpose. Kerosene is dominantly used by households for lighting and may be considered an essential household good. On the other hand, petrol and diesel are overwhelmingly consumed by transporters and rural businesses. Meanwhile, LPG is consumed in very small quantities throughout the survey area and is mainly the preserve of wealthy households.

A major result drawn from this analysis is that the poorest consumers often pay higher energy prices than wealthier buyers. We investigate the reasons behind this result by using regression analysis to estimate the impacts of several market variables on per unit fuel prices. We find that the two most important factors responsible for increasing per unit fuel prices are lack of access to gas stations and the long distances traveled by energy sellers to their fuel sources. Specifically, poor consumers without access to gas stations pay nearly 9 KES (equivalent to $0.11 US) more per liter on average for liquid fuel. Similarly, an energy seller that travels 20 km to their fuel source charges 6 KES (or $0.07 US) more per liter on average than a seller that sources fuels locally. Other likely factors influencing local fuel prices are shown to be infrastructure quality (e.g., the presence of tarmac roads) and local market structure (e.g., the number of stores servicing a commercial center). While these variables are suggested to also influence per unit fuel prices, these results are more ambiguous.

The final area of analysis examines household fuel consumption patterns in our study region in Western Kenya. We test the "energy-stack" model drawn from the literature which suggests that as incomes increase households consume a greater number of fuels without necessarily replacing previously used fuel sources. Our application here is to another detailed survey of 313 households from Western Kenya, in which we examine how households' fuel use compositions change across income levels. Overall, we find that the energy-stack model accurately describes consumption behavior in our sample. Wealthier households are shown to increase their consumption of modern fuels, however, they do not abandon biomass altogether. Nearly all households use both biomass and kerosene at all levels of income, while usage rates of LPG, petrol, diesel, and electricity exhibit sharp increases as incomes rise. Additionally, we find that poor households spend a much higher percentage of their income on energy despite purchasing lower quality fuels. Households in the lowest income group spend nearly 38 percent of their total income on fuel purchases, compared to only 10 percent for the top income group, a finding that is largely consistent with previous literature on fuel expenditures by households (World Bank, 2005). This is despite the fact that poor households only consume relatively cheap fuels (kerosene, firewood, and charcoal), while wealthier households consume significant quantities of more expensive fuels (LPG, petrol, and electricity). This result emphasizes the importance of increasing access to affordable, efficient energy sources for poor consumers.

6.1 Policy Recommendations

The results from our analysis are helpful in identifying and quantitatively assessing the factors that reduce fuel access and increase prices in rural areas in Africa. These results suggest several policy recommendations regarding how to best improve modern fuel access for consumers in Kenya and in Africa, more broadly.

Our first recommendation is to make long-term investments in fuel transportation infrastructure. More efficient infrastructure reduces the costs of moving energy from ports to the hinterland and on to commercial centers. These savings can then be passed onto consumers (in the presence of competitive markets) (Kojima, et al. 2010). Governments should focus on investing their resources in two main areas. First, it is vital that they extend the network of paved roads, as well as improve their overall quality. Having a larger number of paved roads that are of high quality helps to ensure that heavy fuel delivery trucks can operate safely and efficiently. While this poses greater upfront costs to governments, better roads will also require less maintenance in the future and enable fuel supply trucks to access more remote areas. Second, governments should focus on improving pipelines and rail networks. These modes of transport are cheaper than trucking and can therefore decrease the initial transportation cost of moving fuels from the port to the hinterland. This will also reduce the over-reliance of the distribution network on trucks and lower road maintenance expenses.

Our second policy recommendation is to encourage oil marketing companies (OMC) to expand into rural areas. Better access to efficient OMCs will allow more rural consumers to access the cheap fuels these companies provide. Currently, the individual sellers and retail stores are unable to match the economies of scale provided by OMCs. Increasing OMCs' presence in rural communities will allow more consumers to directly access the efficient distribution channels without paying for the high marginal costs of the middlemen. More OMCs will also cut the distance individual sellers must travel to source their fuel, thus reducing the price paid by consumers that still may not have access.

Increasing competition among OMCs can have the benefit of reducing energy sellers' market power in these regions. Currently, many commercial centers are serviced by only one business selling each type of fuel. As local consumers are unable to travel significant distances to purchase fuels, many of these businesses can operate as a monopoly and charge exorbitant prices. Increasing the presence of OMCs within the region can cut prompt these sellers to cut prices in order to remain competitive. Indeed, the results of the analysis from Chapter 3 seem to support the fact that increased competition can reduce fuel prices. While the results on the impact of the number of stores servicing a commercial center were less strong, they suggest that increased competition plays a positive role in reducing per unit fuel prices. According to the results, the presence of each additional energy seller in a commercial center lowered average prices by 1.7 KES per liter. In addition to this direct competition effect, reduced market power in rural areas will encourage firms to pass on any cost savings they achieve to consumers, reducing rent seeking in the industry.

To achieve these results, there are several approaches governments can take to increasing the presence of OMCs in rural markets. First, price controls such as fuel subsidies and caps should be eliminated. Removal of these policies will increase the incentives for OMCs to invest in rural areas by raising the potential revenues companies can gain in these markets (Bacon, 2001). If elimination of price controls is infeasible, governments should at least allow greater flexibility in energy price caps to make rural investments worthwhile for OMCs.

A second approach is a reiteration of our recommendation regarding improving the fuel transportation infrastructure. Investments in this area, particularly improvements in paved roads, may also have the effect of encouraging OMCs to expand into more sparsely populated areas. Higher quality paved road reduce the costs and risks of delivering fuel to remote regions. This in turn allows OMCs to achieve greater profit margins and encourages expansion into rural markets.

Lastly, governments should seek to increase competition among OMCs. An effective, well-regulated competitive market constantly pressures participants to improve efficiency and to share these gains with consumers. The goal of policymakers should not necessarily be to increase the number of firms, as too many small firms do not necessarily improve efficiency in the market (Kojima, et al., 2010). Rather, governments should ensure that firms have the necessary incentives to engage in fair competition and invest in effective fuel delivery.

To achieve this, governments must first make sure that fuel regulations are consistently enforced. Failure to apply fuel safety and quality regulations already on the books allows commercial malpractice to proliferate and reduces the incentives for OMCs to improve their efficiency. For example, a firm will not seek to reduce costs through productivity investments if their competition can offer a lower price by diluting their fuels. In the worst case, firms that do not engage in commercial malpractice can be driven out of the market entirely. Another method to increase competition is to decrease the barriers to entry in the market. This can be achieved by increasing third-party access to large infrastructure, such as storage terminals and bulk procurement systems. This will allow new firms to immediately gain access to the systems necessary to deliver fuel efficiently to rural markets (Kojima, et al. 2010).

Our last policy recommendation is to increase government assistance to households seeking to purchase new, energy-efficient technologies. Evidence from the household data set examined in Chapter 5 indicates that modern fuel use is driven in part by the adoption of new technologies – such as an LPG stove – that require such fuels for their operation, a result that confirms previous research conducted by Foley (2005). However, many poor households cannot afford the large, one-time cost of purchasing these technologies. Thus, a household that would be able to afford the marginal cost of the fuel is kept out of the market due to liquidity constraints. This scenario also applies to households seeking to enter the electricity market. In many cases, they may be able to afford the unit price of electricity use but the high grid connection costs are prohibitive.

To address this problem, governments should implement programs that seek to diffuse, or lower, the one-time cost of these technologies. One possibility is a direct subsidy to promote the use of efficient cooking stoves; however, this may not be sustainable. A second method would be to offer generous payment plans or loans whereby households can spread the one-time costs over a period of several years.

There are many barriers that prevent modern fuel consumption by poor consumers. However, the economic and welfare benefits of increased access to these fuels justify government investments to encourage their adoption. Although certainly not comprehensive, these three policy recommendations, outlined above, will hopefully reduce the costs of supplying modern fuels to the poorest consumers. These policy changes will require significant investments of money and time, although some interventions such as improved enforcement of regulations mostly require political will. Overall, the potential gains from these actions will likely outweigh any costs derived from seeking to improve the energy access situation.

It is worth acknowledging that increasing consumption levels of fossils fuels has serious drawbacks regarding global environmental health. Increased burning of petroleum-based products contributes to the amount of greenhouse gases released into the atmosphere that are causing climate change. It may seem paradoxical to promote economic development through increased fossil fuel consumption which conflicts directly with our environmental goals. However, despite these drawbacks, it could be argued that the burning fossil fuels is at least no worse for the environment than burning biomass to generate an equivalent amount of energy. The burning of biomass, particularly fuelwood and charcoal, also releases significant amounts of greenhouse gases that would otherwise be stored in trees or underground (Bluffstone 1995). Indeed, from an efficiency standpoint, fossil fuels emit lower amounts of harmful greenhouse gases per unit than biomass (Schlag and Zuzarte, 2008). Additionally, excessive biomass consumption may have other negative environmental drawbacks such as deforestation, increased soil erosion, and decreased soil fertility (Cooke, 2008). While renewable energy sources should be promoted and used wherever practical, current fossil fuel consumption is so low in Sub-Saharan Africa that economic development is difficult to imagine without increased consumption of these fuels.

6.2 Future Research

This thesis has sought to examine rural energy markets in Kenya through identification of, and analysis of the impacts of, market inefficiencies on consumers. We have focused specifically on commercial centers, a hitherto understudied area, and how their attributes directly affect energy access to local populations. However, this approach is one of many and there are many additional areas for future research on African energy markets. These markets are highly complex, relatively understudied, and the effectiveness of many proposed policy interventions are largely untested.

One important area of future research would involve a time series analysis of how markets respond as local conditions change. For example, the question of how households respond to a changing energy market environment might be further explored. How quickly do households respond to lowered energy prices and improved access to modern fuels? If households are slow to adopt new fuels, additional efforts may be required to reap the benefits of improved access. Additionally, the responses of independent energy sellers to increased rural competition, particularly the presence of larger OMCs, should be investigated. Answers to this question will add new understanding to the dynamics of rural energy markets and the effectiveness of policy efforts to increase market competition in rural areas.

A second area for future research involves quantifying the economic and welfare benefits that consumers derive from modern fuel adoption. To date, many of these gains have been assumed based on the negative externalities associated with over-reliance on biomass for fuel. An analysis of changing household behavior as they adopt new fuels could help quantify the welfare gains associated with modern fuel use. In turn, this evidence could encourage action by policymakers to promote improved energy access or point to other important steps to increase consumer welfare.

Further investigation into these and other areas that are raised by this research is important. Improved energy access is essential for the future growth prospects of developing countries. Though a better understanding of the how energy markets function in developing countries we can develop better methods to increase sustainable energy access to poor consumers, which can in turn improve the broader economic outlook for the economy as a whole.

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